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Swine Research

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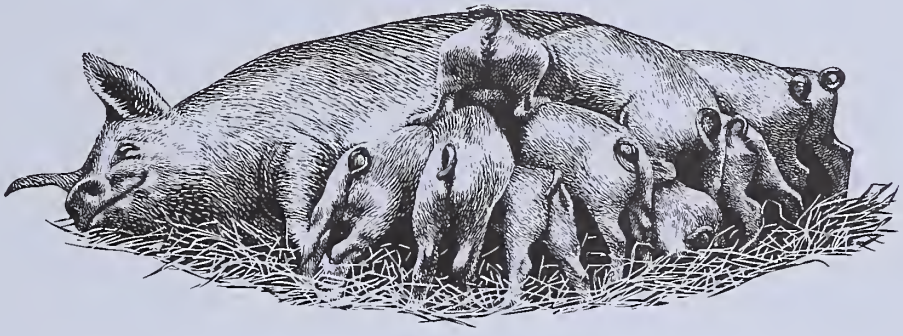
Roman L. Hruska U.S. Meat Animal Research Center
in Cooperation With
University of Nebraska, Agricultural Research Division,
The Institute of Agriculture and Natural Resources



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CONTENTS

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U.S. MEAT ANIMAL RESEARCH CENTER[1]

1. Overview of Center: The U.S. Meat Animal Research Center (MARC) was authorized by Congress on June 16, 1964, thereby creating a single facility that provides an unusual opportunity for making major contributions to the solution of problems facing the U.S. livestock industry. Development of the 35,000-acre facility started in the spring of 1966 and is continuing at the present time. Phase I construction, consisting of an office-laboratory building for intensive investigations, was completed in January 1971. These facilities provide a physical plant for 42 scientists and about 200 support personnel. Phase II construction, consisting of the Meats Research Laboratory and the Biological Engineering Building, was completed in October 1977 and provides a physical plant for 25 scientists and about 60 support personnel. Phase III construction will provide for an Animal Health Systems Research Laboratory. This building is scheduled for completion in 1989 and will accommodate 10 scientists and 20 support personnel. In addition, the University of Nebraska is completing a Veterinary Service-Training Facility in 1989. This facility will provide for four university faculty members, support personnel, and pre- and post-DVM students.

Approximately 50 percent of the research program is devoted to beef cattle, 30 percent to swine, and 20 percent to sheep. Current research program objectives require breeding-age female populations of approximately 7,250 cattle (20 breeds), 4,250 sheep (10 breeds), and 600 crossbred swine litters to carry out the various experiments.

The research program at the Center is organized on a multidisciplinary basis and is directed toward solving problems for the U.S. livestock industry. The research program complements research conducted elsewhere by the U.S. Department of Agriculture and is cooperative with the University of Nebraska Institute of Agriculture and Natural Resources and other land grant university agricultural experiment stations throughout the country.

On October 10, 1978, the President signed into law a bill renaming the U.S. Meat Animal Research Center the Roman L. Hruska U.S. Meat Animal Research Center. The purpose of the bill was to honor former Nebraska Senator Roman L. Hruska for "his efforts in the establishment of a centralized facility for the research, development, and study of meat animal production in the United States."

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[1]Agricultural Research Service-U.S. Department of Agriculture, the University of Nebraska, and other cooperating land grant universities.

2. Overview of Swine Research Program: MARC's swine research program places the highest priority on developing technology capable of having an immediate and long-term impact on the swine industry. The program includes fundamental research and development of technology that can be practically implemented by small farmers and commercial swine producers alike.

Currently, we have 50 research scientist and research associate positions at MARC. There are 33 research projects in beef cattle, sheep, and swine. Thirteen projects are directed toward improving product quality of pork and efficient production of swine.

This report represents a cross section of our swine research program at the present time. Since some of the projects from which results are reported are still in progress, the preliminary nature of some of the results must be recognized. However, it is our opinion that information useful to the industry should be provided at the earliest possible time. Progress reports of this nature will be released periodically to make current results available to the swine industry.

3. Appreciation: I want to express my appreciation to the scientists for their contribution; to Margie McAlhany, MARC Information Officer, for serving as editor; and to Linda Kelly, Secretary to the Director, for proofreading the report.

D. B. Laster, Center Director
Roman L. Hruska
U.S. Meat Animal Research Center

Swine Facilities and Management

Ted W. Acton, Jenell A. Dague, Ed McReynolds, Wayne T. Peshek, Cheryl R. Vap, and Patrick J. Reiman[1]

The Swine Operations Unit provides support (animals, facilities, management, and labor) for the seven research disciplines at MARC. Researchers conduct approximately 40 projects each year in the swine area. These projects require over 4,000 pigs produced from 600 litters in five farrowing seasons. The swine area is staffed with ten full-time employees.

There is currently one 4-way white cross composite maintained in the population. This composite is the result of crosses made with the Yorkshire, Landrace, Chester White, and Large White breeds. In addition, there are two specially selected lines of lean and obese crossbred pigs. These lines were originally developed at the Beltsville Agricultural Research Center (BARC) in Maryland.

The swine area is a specific pathogen-free (SPF) area. The herd was established from lab pigs and has been a closed herd for eight years. Each person entering the area is required to shower and change clothing as a disease-prevention measure. The area is enclosed and all animals maintained in confinement buildings.

New Developments

Importation of three Chinese breeds will occur the summer of 1989. The Agricultural Research Service, in a cooperative agreement with the University of Illinois and Iowa State University, has negotiated with the People's Republic of China to bring the Meishan, Fengjing, and Ming breeds to United States. Research will be conducted to determine their potential usefulness to the swine industry.

The Animal Health Research Unit is the newest discipline at MARC. There are no results published in this progress report, but projects are under way. A research building is being built, and researchers are being recruited.

MARC has into entered a cooperative agreement with the University of Nebraska-Lincoln and Kansas State University that will provide additional training experiences for veterinary students from Kansas and Nebraska beginning in January of 1990. Facilities for faculty, staff, and students are currently nearing completion.

Facilities

All facilities in the swine area (Fig. 1) are total confinement and use a flush system for manure handling. Most of the barns use a negative air pressure ventilation system. Barns that use natural ventilation have screened air inlets to prevent bird access. Nipple waterers are used in all buildings except the farrowing barn.

The breeding and gestation barns (Buildings 61, 62, and 72) have a one-time capacity of approximately 900 head. Stalls are used for boars and for bred females prior to entering the farrowing house. These barns are also used for the collection of puberty data on more than 600 gilts per year.

The farrowing barn (Bldg. 60) has 96 farrowing crates. These are conventional 5 x 7 ft crates installed on a partially slotted concrete floor. There is hot water heating in the floor under the creep areas of the pens. Electric heat lamps are used the first few days after farrowing.

The nursery barn (Bldg. 67) has capacity for approximately 880 pigs. Two of the rooms have raised, expanded-metal decks and the other two have concrete floors

The finishing barns (Bldgs. 64, 65, 66, 69, 70, and 73) have a one-time capacity of approximately 1,500 head. Feeders and feed can be weighed in all barns to obtain feed efficiency data. Animal scales are available in barns.

A special-use barn (Bldg. 68) is designed for projects that require special pen arrangements or utilize small numbers of animals. The surgery building (Bldg. 63) has a penned recovery area, a prep room, and a surgery room. Approximately 500 surgeries are performed annually. Building 74 is the shower facility.

Standard Management Practices

Breeding is done by single-sire mating. When females are detected in estrus, they are bred and then rebred approximately 24 hr later. Information collected at breeding (animal numbers, date, breed, pen location, and standing score) is recorded and stored in a database computer system. Numerous lines are maintained within each population to minimize inbreeding.

Gilts entering the breeding herd are vaccinated for erysipelas, leptospirosis, pseudorabies, and parvovirus prior to the breeding season. Eighty percent of the farrowings are gilts, and no female remains in the herd for more than three farrowings. All females are fed 3 ½ lb standard gestation ration (Table 1) through breeding and the first part of gestation. During the last month of gestation, they are fed 4 lb of the same ration. Females are housed in group pens (10 to 20 head per pen) during breeding and most of gestation. They are maintained in gestation crates for at least two weeks prior to entering the farrowing house.

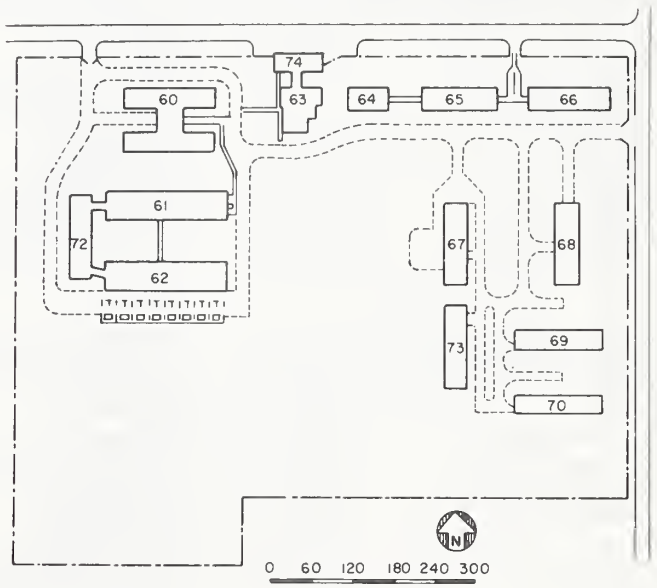

Figure 1—KEY TO BUILDINGS.

60. Farrowing	67. Nursery
61. Breeding and Gestation	68. Special-Use
62. Breeding and Gestation	69. Finishing
63. Surgery	70. Finishing
64. Finishing	72. Breeding and Gestation
65. Finishing	73. Finishing
66. Finishing	74. Shower

[1]Acton is the swine operations manager; Dague is an agricultural research technician, growing-finishing area; McReynolds is an agricultural research technician, breeding and gestation area; Peshek is an agricultural research technician, farrowing and nursery area; Reiman is an agricultural research technician, feedmill; and Vap is a clerical assistant, MARC.

The farrowing house is basically managed as an all-in/all-out facility, with the concrete floor cleaned, disinfected, and sealed between farrowings. Females enter the farrowing house at 110 days of gestation. They are weighed and fed the standard lactation ration (Table 2). The feeding rate is reduced at farrowing and then is adjusted to individual requirements, which are dependent upon litter size and condition. At weaning, sows are weighed and returned to the gestation barns to be rebred or sold.

Piglets are processed within 24 hr of birth. Processing involves notching ears, docking tails, clipping needle teeth, and injecting iron dextran. Data collected at farrowing include birth weight, nipple count, sex, vigor, sow temperature, and nervous score. At 14 days, a second injection of iron dextran is given, and males not retained for breeding are castrated. The standard creep ration (Table 3) is offered at this time.

Weaning occurs at 28 days of age. Pigs are weighed and transferred by litter to the nursery (10 to 12 pigs per pen). They are started on the standard creep ration for a few days and then gradually introduced to the standard nursery ration (Table 4) to minimize stress. At 8 weeks of age, all pigs are weighed and assigned to pens, and most pigs are moved to finishing pens by 10 wk of age. The nursery is managed as an all-in/all-out system, with cleaning and disinfecting conducted between each group. The temperature is maintained at 76 to 80° F throughout the nursery phase.

During the growing-finishing phase, pigs are fed *ad lib* the standard grower ration (Table 5) until approximately 140 lb and then the standard finishing ration (Table 6) until market weight (avg 220 lb). Finishing barns are managed as an all-in/all-out system as much as possible. Pens are cleaned and disinfected and the floors sealed between groups.

Standard Rations

All swine diets are ground and mixed in a horizontal, paddle-type mixer at the MARC feedmill. Vitamin and trace mineral supplements are described in Tables 7 and 8.

Table 1—Gestation diet

Ingredient	%
Corn	84.1
Soybean meal	11.0
Dehydrated alfalfa	1.0
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 2—Lactation diet

Ingredient	%
Corn	76.0
Soybean meal	19.1
Dehydrated alfalfa	1.0
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 3—Creep diet

Ingredient	%
Corn	40.2
Soybean meal	30.0
Steamed rolled oats	10.0
Dicalcium phosphate	3.5
Limestone	0.3
Whey	5.0
Dextrose	5.0
Fat	5.0
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 4—Starter diet

Ingredient	%
Corn	55.8
Soybean meal	25.0
Dicalcium phosphate	2.4
Limestone	0.8
Oats	10.0
Whey	5.0
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 5—Grower diet

Ingredient	%
Corn	76.5
Soybean meal	19.6
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 6—Finishing diet

Ingredient	%
Corn	82.1
Soybean meal	14.0
Dicalcium phosphate	2.4
Limestone	0.5
Iodized salt	0.4
Vitamin Premix #9	0.2
Trace mineral G	0.2
Choline chloride	0.2

Table 7—Vitamin premix #9

Ingredient	Quantity
Vitamin A	1,200,000 IU/lb
Vitamin D	160,000 IU/lb
Vitamin E	8,000 IU/lb
Vitamin K	800 mg/lb
Riboflavin	1,200 mg/lb
d-Pantothenic Acid	4,800 mg/lb
Niacin	6,400 mg/lb
Vitamin B_{12}	6 mg/lb
Thiamine	500 mg/lb
Biotin	50 mg/lb
Folic Acid	200 mg/lb

Table 8—Trace mineral G

Ingredient	%
Calcium	15.000
Copper	0.500
Iron	8.000
Manganese	1.000
Zinc	5.000
Selenium	0.005

Performance of Eight Purebred and Two Composite Swine Populations

Larry D. Young, Gordon E. Dickerson, and Kreg A. Leymaster[1]

Introduction

Two long-term breeding projects were conducted at MARC to evaluate the development of composite lines as a specific method of utilizing heterosis and differences among breeds. Composite lines are self-propagating populations developed from a crossbred foundation. After the initial crossing, all replacement animals came from within the population. Theoretically, a composite line developed from a crossbred population with equal contribution from four breeds should retain 75% of the initial heterozygosity and, hypothetically, 75% of the initial heterosis. The objective of this report is to summarize reproduction, growth, carcass, and puberty data obtained on eight pure breeds and two four-breed composite populations. In addition, data will be presented on the amount of heterosis retained in the various generations of composite populations.

Procedure

Chester White, Swedish Landrace, Large White, Yorkshire, and the associated crossbred populations farrowed during February of each year (spring season). Duroc, Hampshire, Pietrain, Spot, and associated crossbred populations farrowed annually during September and October (fall season).

The breed types of litters produced in each year are shown in Table 1. In 1980 the following two-way crosses were made: Chester White boars x Large White females and Yorkshire boars x Landrace females in the spring season and reciprocal crosses of Duroc x Pietrain and Hampshire x Spot in the fall season. In 1985, all possible two-way crosses were made among contemporary purebreds in both seasons. In 1981 and 1986, four-breed cross litters (F_1) were farrowed by making all possible four-breed cross matings within a season. In 1982, F_2 litters were produced by matings among F_1 males and females. Similarly, F_3, F_4, F_5, and F_6 litters were farrowed in 1983, 1984, 1985, and 1986, respectively. Hereafter, F_3 and later generations will be considered identical genetically and will be referred to as F_3.

Pigs were raised by their own dams and had access to creep feed at 14 days of age. Pigs were weaned at 28 days of age into a nursery, weighed at 56 days of age, and moved to growing-finishing facilities 1 wk later. Two boars and up to two barrows per litter were penned together, while gilts were penned in groups of 20 per pen. Growth was measured from 70 to 154 days of age. Carcass data were obtained on barrows slaughtered at about 220 lb liveweight. Gilts were moved to another building at 154 days of age and checked daily for estrus to about 9 mo of age.

Results

Data from spring and fall were analyzed separately. Thus, comparisons between breeds in different seasons may include season effects as well as real breed differences. The model for litter traits and puberty traits included the effects of year and breed. The model for preweaning weight and postweaning growth included the effects of year, breed, and sex; the linear effect of weight was added to the model for backfat probe. The model for carcass traits included the effects of year, breed, linear effect of carcass weight, and the interaction of the linear effect of carcass weight with breed.

The mean performance of the eight purebreds and the various crossbred generations involved during the development of the associated composite lines is shown in Tables 2 through 5 for several preweaning and postweaning traits. Also shown are the comparisons of each crossbred generation with the average performance of the purebreds. This comparison is an estimate of the net individual, maternal, and paternal heterosis retained in the crossbred generation. The F_3 and subsequent generations of the composite lines are expected to have 75% as many heterozygous loci as the F_1. If heterosis is retained in proportion to heterozygosity, the F_3 is expected to retain 75% of the heterosis present in the F_1. If the comparison "F_3-3/4F_1-1/4P" is equal to zero, then 75% of the initial heterosis was maintained in the F_3; positive values indicate more than 75% was retained, while negative values indicate less than 75% was retained. For brevity in the discussion, this comparison will be referred to as "recombination effects," which is the genetic mechanism that would cause heterosis not to be retained in proportion to heterozygosity.

Evaluation of the differences among breed group means can be accomplished by examining Tables 2 through 5. It should be noted that the results for the F_2 generation are based on much smaller numbers than are the results for the other generations and thus are more susceptible to error. Some discussion of the recombination effects in the F_3 will be presented.

Recombination effects were significant and positive for litter traits in the spring farrowing, indicating better than expected performance. However, the estimates of recombination effects for litter traits were negative, small, and nonsignificant in the fall season. This difference between seasons reflects the different levels of heterosis in the F_1s. Initial heterosis in the F_1 for litter traits was relatively small in the spring but large and positive in the fall. Note that the F_3s in the spring and fall have a similar advantage over their respective purebred means.

Recombination effects on average pig birth weight were significantly negative in the spring but nearly zero in the fall. Recombination effects on average pig weaning weight were nonsignificantly negative in the spring but significantly positive in the fall. While these differences were statistically significant, they were relatively small in magnitude and likely reflect the effect of differences in litter size on pig growth.

Recombination effects on postweaning daily gain were essentially zero in both seasons, despite significant positive estimates for initial heterosis for this trait. Recombination effects on probe backfat thickness at 180 lb liveweight were zero in the spring but positive and significant in the fall. The positive value in the fall is relatively small but is undesirable because the pigs were fatter than expected.

Estimates of recombination effects on carcass length and carcass backfat were not significant in either season. However, recombination effects on loin eye area were significant, undesirable, and of similar size in the two seasons. Initial heterosis for loin eye area was also positive and similar in the two seasons.

For percent cycling in the spring season, the initial heterosis was very small, and recombination effects were slightly negative but not significant. However, initial heterosis for age at puberty of gilts born in the spring was significant, large, and desirable, while recombination effects were significant and undesirable. In contrast, initial heterosis and recombination ef-

[1]Young is a research geneticist, Dickerson is a research collaborator, and Leymaster is a research geneticist, Genetics and Breeding Unit, MARC.

fects for percent cycling and age at puberty were all desirable and significant for gilts born in the fall season.

In summary, it appears that the importance of recombination effects depends upon the trait, the breeds contributing to the composite, and, possibly, differences in environment caused by such things as season of birth. With the exception of age at puberty in the fall and loin eye area in both seasons, it appears that the estimates of recombination effects are near zero or positive. Positive values mean more heterosis was retained than expected, which is a bonus. These results indicate that the development of composite lines would generally be a viable method of utilizing heterosis and differences among breeds.

Table 1—Breed types of litters produced in each year[a]

Breed type	1979	1980	1981	1982	1983	1984	1985	1986
Purebred	X	X	X	X	X	X		
Two-breed cross		X					X	
F_1[b]			X					X
F_2[c]				X				
F_3[d]					X	X	X	X

[a]Purebred Chester White, Landrace, Large White, Yorkshire, and their crosses were produced in the spring. Purebred Duroc, Hampshire Pietrain, Spot, and their crosses were produced in the fall.

[b]F_1 (four-breed cross) produced from matings among different two-breed crosses.

[c]F_2 produced from matings among F_1 crosses.

[d]F_3 produced from matings among F_2 crosses.

Table 2—Breed means and comparisons among means for preweaning traits in the spring season

		Litter traits					Pig traits	
Litter breed	No. litters	Total no. born[a]	No. born alive	No. weaned	Litter birth wt, lb[b]	Litter weaning wt, lb	Avg pig birth wt, lb	Avg pig weaning wt, lb
Yorkshire (Y)	124	8.51	7.79	6.77	20.30	88.2	2.36	13.05
Landrace (L)	129	9.33	8.78	7.58	28.44	101.4	2.93	13.34
Large White (W)	127	8.23	7.72	6.47	20.59	85.5	2.42	13.32
Chester White (C)	102	8.27	7.57	5.31	21.23	69.2	2.55	13.14
Two-breed crosses (TW)	103	8.96	8.56	7.61	25.51	108.9	2.79	14.35
F_1	107	8.61	8.34	7.54	25.51	112.4	2.96	15.04
F_2	32	9.44	9.08	7.47	26.30	106.7	2.76	14.26
F_3	231	9.52	8.92	8.01	27.07	115.5	2.80	14.48
Comparison								
TW-P		.38	.59	1.08[d]	2.87[d]	22.7[d]	.22[d]	1.15[d]
F_1-P		.02	.38	1.01[d]	2.87[d]	26.2[d]	.39[d]	1.83[d]
F_2-P		.86	1.11[d]	.93	3.66[d]	20.7[d]	.20[d]	1.06[d]
F_3-P		.93[d]	.95[d]	1.48[d]	4.43[d]	29.3[d]	.23[d]	1.28[d]
F_3-3/4 F_1-1/4P[c]		.92[d]	.67[d]	.72[d]	2.27[d]	9.7[d]	-.06[d]	-.11

[a]Total of pigs born alive and stillborn.

[b]Includes wt of stillborn pigs as well as those born alive.

[c]This contrast estimates recombination effects (see text).

[d]Significantly different from zero at $P<.05$.

Table 3—Breed means and comparisons among means for preweaning traits in the fall season

Litter breed	No. litters	Litter traits: Total no. born[a]	Litter traits: No. born alive	Litter traits: No. weaned	Litter traits: Litter birth wt, lb[b]	Litter traits: Litter weaning wt, lb	Pig traits: Avg pig birth wt, lb	Pig traits: Avg pig weaning wt, lb
Hampshire (H)	136	7.95	7.46	5.84	21.19	75.8	2.62	12.96
Duroc (D)	139	8.93	8.10	6.43	24.56	79.4	2.69	12.30
Pietrain (P)	135	7.35	6.76	5.49	19.95	68.3	2.68	12.43
Spot (S)	147	7.93	7.14	4.85	23.35	65.5	2.92	13.56
Two-breed crosses (TW)	110	7.22	6.65	5.13	21.38	73.2	2.92	14.48
F_1	99	9.47	8.88	7.88	29.48	110.2	3.06	14.07
F_2	36	10.63	10.11	8.14	30.62	107.8	2.85	13.01
F_3	238	8.97	8.29	6.95	27.36	98.3	2.99	14.24
Comparison								
TW-P		-.82[d]	-.71	-.52	-.88	.88	.20[d]	1.68[d]
F_1-P		1.43[d]	1.52	2.23[d]	7.21[d]	37.9	.34[d]	1.26[d]
F_2-P		2.59[d]	2.74[d]	2.49[d]	8.38[d]	35.7	.13[d]	.20
F_3-P		.93[d]	.93[d]	1.30[d]	5.11[d]	26.0	.26[d]	1.43[d]
F_3-3/4 F_1-1/4P[c]		-.14	-.21	-.37	-.31	-2.6	.01	.51[d]

[a]Total of pigs born alive and stillborn.

[b]Includes wt of stillborn pigs as well as those born alive.

[c]This estimates recombination effects (see text).

[d]Significantly different from zero at $P<.05$.

Table 4—Breed means and comparisons among means for postweaning traits in the spring season

Litter breed	No. observations[a]	Daily gain by day[bc]	Carcass traits[e]: 10th rib backfat, in[bd]	Carcass traits[e]: Length, in	Carcass traits[e]: 10th rib backfat, in	Carcass traits[e]: Loin eye area, in^2	Puberty traits: Percent cycling[f]	Puberty traits: Age at puberty[g]
Yorkshire (Y)	644/120/336	1.56	.65	30.75	1.11	5.27	78.8	225.6
Landrace (L)	696/145/348	1.63	.62	32.20	.99	4.67	91.8	187.9
Large White (W)	630/113/333	1.68	.60	31.69	.97	4.93	93.3	211.2
Chester White (C)	417/51/224	1.51	.67	30.46	1.07	4.99	81.3	218.6
Two-breed crosses (TW)[h]	541/119/259	1.72	.66	31.36	1.11	4.91	87.3	199.1
F_1[i]	438/113/263	1.74	.66	31.44	1.07	5.21	85.8	195.8
F_2[i]	175/33/100	1.71	.63	31.20	1.02	4.94	96.1	205.6
F_3[i]	1146/263/520	1.70	.66	31.52	1.06	4.79	82.7	207.8
Comparison								
TW-P		.12[i]	.03[i]	.08	.07	-.05	-1.0	-11.7[i]
F_1-P		.14[i]	.03[i]	.17	.03	.25[i]	-.4	-15.0[i]
F_2-P		.11[i]	-.01	-.17	.00	-.03	9.8[i]	-5.2
F_3-P		.10[i]	.02[i]	.24[i]	.02	-.22[i]	-3.6	-3.0
F_3-3/4 F_1-1/4P[h]		-.00	.00	.11	-.00	-.40[i]	-3.3	8.2[i]

[a]Number of observations for growth and backfat/carcass traits/puberty traits.

[b]Average of boar, barrow, and gilt data.

[c]Average daily gain from 70 to 154 days of age.

[d]Adjusted to 180 lb liveweight.

[e]Adjusted to 165 lb carcass weight.

[f]Percentage of gilts with at least one estrus.

[g]Based on gilts exhibiting estrus.

[h]This contrast estimates recombination effects (see text).

[i]Significantly different from zero to $P<.05$.

Table 5—Breed means and comparisons among means for postweaning traits in the fall season

Litter breed	No. observations[a]	Daily gain by day[bc]	Carcass traits[e]				Puberty traits	
			10th rib backfat, in[bd]	Length, in	10th rib backfat, in	Loin eye area, in^2	Percent cycling[f]	Age at puberty[g]
Hampshire (H)	616/107/241	1.54	.52	30.71	1.04	5.49	77.4	210.3
Duroc (D)	686/114/283	1.56	.62	30.48	1.13	4.81	80.3	234.4
Pietrain (P)	588/72/288	1.41	.56	28.59	1.30	5.77	87.9	204.7
Spot (S)	581/94/237	1.68	.51	30.99	1.04	5.18	89.4	201.1
Two-breed crosses (TW)	456/79/229	1.73	.54	30.43	1.06	5.55	93.2	195.3
F_1	493/119/235	1.75	.53	30.40	1.09	5.58	93.7	200.3
F_2	192/32/99	1.72	.55	29.38	1.20	5.19	93.0	200.0
F_3	1145/230/593	1.68	.56	30.53	1.11	5.22	97.2	192.2
Comparison								
TW-P		.18[i]	-.01	.23	-.07	.22	9.5[i]	-17.4[i]
F_1-P		.20[i]	-.02	.21	-.04	.29[i]	10.0[i]	-12.3[i]
F_2-P		.17[i]	-.01	-.81[i]	.08	-.14	9.3[i]	-12.7[i]
F_3-P		.13[i]	.01	.35[i]	-.01	-.11	13.5[i]	-20.4[i]
F_3-3/4 F_1-1/4P[h]		-.02	.03[i]	.19	.01	-.33[i]	6.0[i]	-11.2[i]

[a]Number for growth and backfat/number for carcass traits/number for puberty traits.
[b]Average of boar, barrow, and gilt data.
[c]Average daily gain from 70 to 154 days of age.
[d]Adjusted to 180 lb liveweight.
[e]Adjusted to 165 lb carcass weight.
[f]Percentage of gilts with at least one estrus.
[g]Based on gilts exhibiting estrus.
[h]This contrast estimates recombination effects (see text).
[i]Significantly different from zero to $P<.05$.

Estimation of Carcass Leanness by Use of X-ray Computed Tomography

Kreg A. Leymaster[1, 2]

Introduction

The relative amount of muscle and fat tissues in the carcasses of livestock is often referred to as carcass composition. Livestock industries and consumers are greatly concerned about carcass composition because it relates to the cost of production and product quality. Excessive fat is economically inefficient to produce and detrimental to product acceptability. Consumers seek nutritious, wholesome meat that is low in saturated fat and cholesterol content. Consequently, the reduction of fat and the improvement of carcass leanness are urgent goals of the livestock industries.

Animal scientists and producers often want to know the composition of live animals or of carcasses without sacrificing either animals or carcasses. This is a difficult task, and considerable resources have been committed to development and evaluation of numerous methods to estimate the composition of live animals. Accurate, nondestructive methods are needed. Many techniques have been tried with varying degrees of success. Ultrasonic machines have probably received the most widespread use, and developments in diagnostic medicine continue to evolve ultrasonic technology. However, there is still considerable opportunity for improvement.

X-ray computer assisted tomography, commonly referred to as CAT scanning, is a more sophisticated diagnostic instrument also developed for human medicine. The potential of computed tomography to advance animal science research and production was first recognized by the Animal Breeding and Genetics Department of the Agriculture University of Norway in 1980. Based on encouraging results of a pilot trial, the Department acquired an X-ray computer tomograph in 1982. The author spent 9 mo in Norway during 1983 to help calibrate the computer tomograph for estimation of carcass composition. The purpose of this article is to provide information concerning general principles of computed tomography, experimental procedures for animals, interpretation of images, and preliminary results of estimating composition in swine.

Procedure

Principles of computed tomography. Computed tomography uses data obtained by transmitting X-rays through a subject in many directions to construct an image of a cross-sectional slice through the subject. Differences in densities of muscle and fat tissues affect the intensity of radioactive energy that passes through the tissues. The procedure uses an X-ray tube positioned opposite a battery of 512 detectors that measure received intensities of X-rays. As the assembly rotates around the subject, pulses of radiation are generated (Fig. 1). During a single scan, 240, 360, or 720 pulses of radiation are generated, corresponding to scanning times of about 3, 5, or 10 sec, respectively. With each pulse, 512 measurements of radioactive energy that have been transmitted through the subject are collected by the detectors. A computer processes information from the detectors to yield the cross-sectional image of the subject. The image is a matrix of 65,536 values that may range from -1024 to 1023 computed tomography units. The values are converted to a grey scale to display the image on a viewing screen at the operator's console. Each value represents the density of a volume of tissue potentially as small as .000006 cubic inches. Tissues are easily distinguished from one another as muscle ranges from about 40 to 160, fat from about -120 to -20, and bone from about 300 to 1,000. An image taken at the last rib of a market-weight pig is shown in Figure 2.

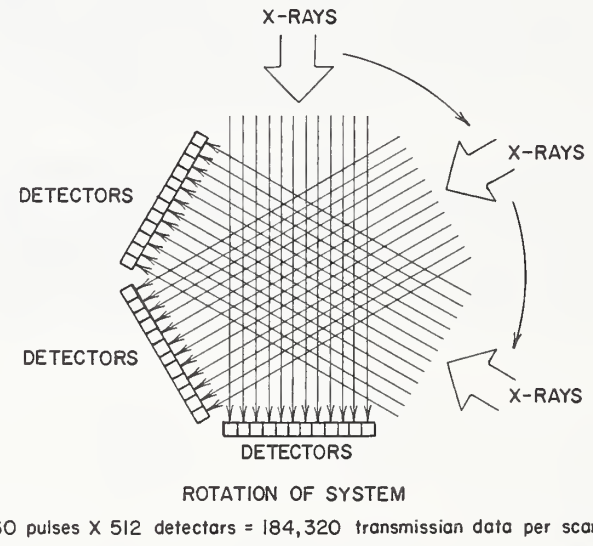

Figure 1—Illustration of X-ray tube and detector assembly rotating around patient.

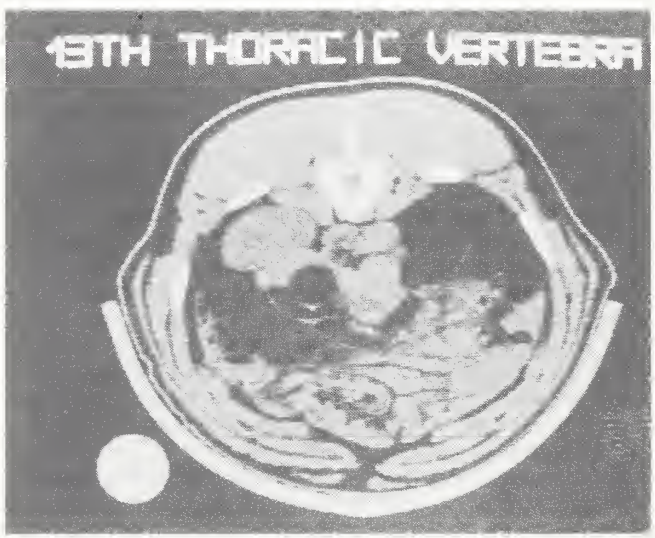

Figure 2—Example of a cross-sectional image taken at the last rib of a pig.

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[2]The author would like to acknowledge Harald Skjervold, Nils Standal, Petter Heyerdahl, Erling Sehested, Kjell Petterson, Knut Dalen, Odd Vangen, and Paul Allen for their support and assistance.

Experimental procedures for animals. Animals were fasted at least 16 hr prior to scanning and were given a tranquilizer followed by an anesthetic to reduce movement during scanning. It was not necessary to anesthetize sheep. Animals were placed on a plexiglass cradle, weighed, and restrained. A profile of the animal was produced to standardize scanning locations, for example, the last rib. Scans were then taken at the desired locations. After scanning was completed, the images were stored on magnetic media for later analyses.

Following scanning, animals were slaughtered and carcasses split into two sides. One side of each carcass was separated into bone and soft tissue. The soft tissue was ground, and a sample was chemically analyzed to determine proportions of water, fat, and protein. The tomographical data could then be related to carcass composition by using statistical procedures. This is the method for calibrating the computer tomograph to estimate composition. If the tomographical data provides an accurate estimation of carcass composition, then computed tomography could be used on live animals to determine composition without sacrificing the live animals.

Results

Interpretation of images. Computer programs were developed to isolate the values corresponding to the part of the image of interest. For example, the carcass was separated from organs, air, and the plexiglass cradle. The desired values were then summarized as a histogram to illustrate the frequency that each value was represented. A histogram is shown in Figure 3.

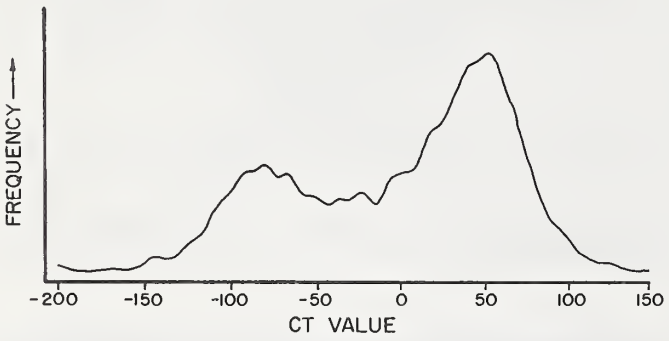

Figure 3—Histogram showing frequency of values for soft tissue of carcass.

Inspection of the bimodal histograms suggested the presence of two underlying histograms corresponding to muscle and fat tissue. To examine this concept, values representing the loin eye muscle were defined. The resulting muscle histogram was superimposed on the original histogram (Fig. 4). Muscle tissue accounted for about 55% of the values in this particular image. In a similar manner, the histogram corresponding to fat tissue was defined and superimposed on the original histogram (Fig. 5). About 30% of the values in the original histogram were attributable to fat tissue. If one considers the muscle and fat histograms together, about 15% of the original histogram is unexplained. This residual portion is illustrated in Figure 6 and corresponds to values representing a mixture of both fat and muscle tissue.

If this biological interpretation of histograms is reasonably appropriate, then the concepts can be used to measure differences among animals in composition. As an example, histograms of known fat (solid line) and lean (dashed line) pigs of equal weight are illustrated in Figure 7. The histograms show that the fat pig had more values in the range corresponding to fat tissue and fewer values in the range corresponding to muscle tissue than did the lean pig.

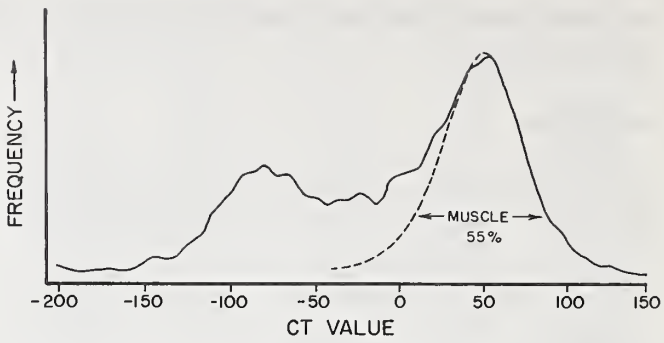

Figure 4—Underlying histogram showing that muscle tissue represents 55% of the soft tissue in the carcass.

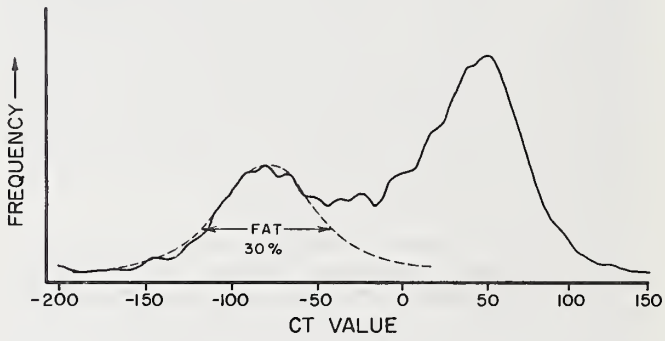

Figure 5—Underlying histogram showing that fat tissue represents 30% of the soft tissue in the carcass.

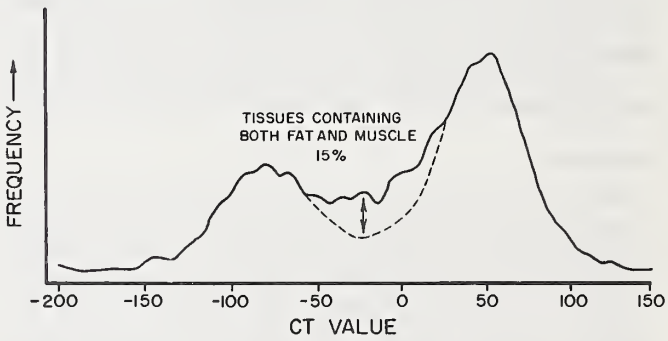

Figure 6—Remaining values that represent a mixture of both muscle and fat tissues.

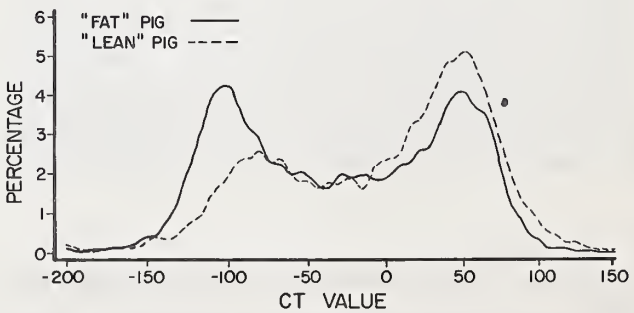

Figure 7—Histograms of fat and lean pigs showing the different frequencies of muscle and fat tissues.

Preliminary results in swine. An experiment to calibrate the computer tomograph was conducted using 48 pigs weighing about 70 lb. Scans were taken at 11 locations on each animal, and tomographical data were used to estimate the percentage protein, fat, and water in soft tissue. Information at each scanning location accounted for significant variation in percentage fat and water. Results indicated that, as the computed tomography value increased, there was a decrease in percentage fat, an increase in percentage water, and a slight increase in percentage protein.

It was demonstrated that X-ray computed tomography can be used to predict composition with a relatively high degree of accuracy. As a consequence of the initial research in Norway, several institutions have also started research programs using computed tomography and other more recently developed diagnostic instruments. This exciting technology is even being applied to improve the national breeding herds of swine and sheep in Norway, and similar goals are planned in Hungary.

Selection for Components of Litter Size and Expected Results

Kreg A. Leymaster, Larry D. Young, Gary L. Bennett, and Ronald K. Christenson[1]

Introduction

Production efficiency of swine could be improved by increasing litter size at birth. Like most economically important traits, however, litter size is physiologically complex. Litter size represents the final expression of numerous component traits that interact in ways that are not fully understood. The failure to comprehend the complexity of litter size limits the opportunities for improvement. Modeling is a research tool that can be used to help understand the interrelationships among component traits that determine litter size. It is, therefore, important to develop models of litter size that attempt to integrate the existing knowledge about component traits and their effects on litter size.

A model of litter size based on ovulation rate, uterine capacity, and potential viability has been proposed. The model is described in a separate article in this swine progress report, and examples are presented to illustrate the concepts. Very briefly, prenatal mortality is divided into two distinct phases. The first phase represents the reduction of ova shed to potentially viable embryos. These obligatory losses are considered inherent to the ovum/embryo and not directly associated with limitations of the maternal environment. The second phase consists of the reduction of potentially viable embryos to pigs at birth. This reduction is a consequence of the number of potentially viable embryos exceeding the uterine capacity of the dam. Uterine capacity refers to the litter size of a female when ovulation rate is very high (the largest litter the female can produce). This model of litter size thus incorporates the concept of uterine capacity by allowing its interaction with ovulation rate and potential viability to determine prenatal mortality.

The model can be used to predict the outcome of various methods of selecting for increased litter size. The usefulness of the predictions depends on how accurately the model describes actual reproductive characteristics. Comparison of predicted and actual values is a method of validating the model. This method of validation is limited to the extent that appropriate information is available to use for comparative purposes. It may be necessary to design an experiment with animals for the specific purpose of generating actual data to validate the model efficiently.

The purpose of this article is twofold; first, to present the results of simulating several selection schemes based on the proposed model of litter size, and second, to describe an actual selection experiment being conducted with swine to provide information for validating the proposed model of litter size.

Procedure

Simulated selection. Direct selection for ovulation rate, uterine capacity, litter size, and embryo survival and selection for indexes of ovulation rate with each of the remaining traits were simulated. The index of ovulation rate and uterine capacity was derived so the expected gain in uterine capacity was 95% of the expected gain in ovulation rate. This ratio represents the relative avg of uterine capacity and ovulation rate that was assumed in the base population. The index of ovulation rate and embryo survival was calculated based on the generally accepted model of litter size as the product of ovulation rate and embryo survival. The index of ovulation rate and litter size was derived with litter size as the selection objective.

Selection was simulated by generating 1,000 litter records per selection line each generation. Heritabilities of ovulation rate and uterine capacity were assumed to be .25 and .20, respectively, and uncorrelated genetically and phenotypically. No additional genetic variation was assumed. Selection of replacement males and females was based on the record of their dam. Replacement males were chosen from the top 10% of litters, whereas replacement females were chosen from the top 30% of litters. Ten generations of selection were simulated.

Actual selection. It was decided to design a selection experiment with swine that would provide data to validate several key assumptions in the proposed model. Specifically, no information was directly available in the literature on the heritability of uterine capacity and its genetic correlation with ovulation rate. An appropriate design to estimate these parameters is to practice single-trait selection directly for ovulation rate and uterine capacity. The line selected for ovulation rate will eventually provide information about the heritability of ovulation rate and the genetic correlations of ovulation rate with uterine capacity, litter size, and embryo survival. Similarly, the line selected for uterine capacity will allow the heritability of uterine capacity and its genetic correlations with ovulation rate, litter size, and embryo survival to be estimated.

To actually practice selection for ovulation rate and uterine capacity, one must be able to measure each trait on individual females. Ovulation rate can be determined by use of a laparoscope. Uterine capacity is more difficult to measure, because natural ovulation rate may be less than the true uterine capacity. However, when ovulation rate is very high, litter size at birth is a measure of uterine capacity. Therefore, a procedure is needed to ensure that each female ovulates at a high rate so uterine capacity is expressed. Superovulation (SO), treatment with exogenous hormones, is often used to increase ovulation rate. A surgical procedure, unilateral ovariectomy, causes the remaining ovary to produce the same total number of ova as females with two ovaries. Therefore, if an ovary and the adjacent uterine horn are both surgically removed, unilateral ovariectomy-hysterectomy (UHO), the number of ova in the remaining uterine horn is twice the normal rate. The remaining uterine horn is consequently challenged with additional ova as desired.

The procedures of SO and UHO were therefore considered as alternative methods to measure uterine capacity. The literature was reviewed to determine which procedure was most appropriate. Information from 11 experiments that included control, SO, and/or UHO groups of gilts was used. Data on ovulation rate, embryo survival, and litter size at 25 to 35 days of gestation were analyzed. Accounting for variation among experiments, ovulation rates of control, SO, and UHO gilts averaged 6.1, 12.9, and 11.8 ova per uterine horn, respectively. Therefore, both SO and UHO resulted in significant increases in ovulation rate per uterine horn. The avg number of fetuses at about 30 days of gestation was 4.7, 6.6, and 8.4 fetuses per uterine horn for control, SO, and UHO gilts, respectively. Although gilts subjected to SO and UHO treatments had more fetuses than control gilts as desired, UHO gilts produced more fetuses than SO gilts despite having lower ovulation rates. Embryo survival was 72% in UHO gilts but only 52% in SO gilts. These results favored UHO over SO as a procedure to measure urine capacity.

[1]Leymaster and Young are research geneticists, Genetics and Breeding Unit; Bennett is the research leader, Production Systems Unit; and Christenson is the research leader, Reproduction Unit, MARC.

Additional support was provided by evaluating litter size at birth in SO and UHO gilts. Ovulation rate and litter size at birth were recorded on control and SO gilts at the University of Missouri and on control and UHO gilts in a preliminary study at MARC. Control gilts averaged 6.8 ova and 4.7 pigs per uterine horn compared to 10.2 ova and 5.0 pigs per uterine horn in SO gilts. The SO gilts with higher ovulation rates produced only 6% more pigs at birth than control gilts. However, control gilts at MARC averaged 5.9 ova and 4.5 pigs per uterine horn compared to 11.9 ova and 5.7 pigs per uterine horn in UHO gilts. The UHO gilts produced 27% more pigs per uterine horn than the control gilts. Based on the evidence, UHO provided a better environment for the expression of uterine capacity than SO.

A selection experiment with swine was started in 1986. Single-trait selection lines were established for uterine capacity and ovulation rate. Selection is based on the dam's record for either uterine capacity or ovulation rate, with replacement boars and gilts taken from the best one-third of litters. Uterine capacity is measured as the litter size at birth of UHO gilts. Each selected line uses 36 boars and 108 farrowing gilts per generation, split evenly into two replicates. An unselected control line is maintained with 10 boars and 20 farrowing gilts per replicate. Inbreeding per generation within a replicate is 0.9% for the selected lines and 1.1% for the control line, based on theoretical calculations.

Results

Simulated selection. Predicted responses due to simulated selection are presented in Table 1. Direct selection for litter size produced an increase of 2.13 pigs. Direct selection for each of the component traits — ovulation rate, uterine capacity, and embryo survival — resulted in less change in litter size than selection directly for litter size. Selection for embryo survival actually decreased litter size slightly. Selection for the index of ovulation rate and uterine capacity resulted in the greatest increase in litter size, being 39% more effective than direct selection for litter size. The indexes of ovulation rate with either embryo survival or litter size gave greater responses in litter size than selection directly for litter size, but were less effective than the index of ovulation rate and uterine capacity.

The responses in litter size are due to the changes in ovulation rate and uterine capacity brought about from the different selection schemes. The relative emphasis on ovulation rate and uterine capacity is reflected in the changes in embryo survival. Thus, selection solely for ovulation rate significantly decreased in embryo survival because the extra ova could not be supported without improving uterine capacity. Direct selection for litter size resulted in similar increases in ovulation rate and uterine capacity; therefore embryo survival did not change. The three indexes resulted in slight declines in embryo survival.

The results of simulating selection directly for litter size agree well with selection experiments in mice. In addition, the model of litter size predicts the results of selection schemes that have not yet been tested with animals. It does provide some guidance as to which selection schemes may be most useful for application.

Actual selection. The second generation of selection for either ovulation rate or uterine capacity in swine will be completed during 1989. This is a long-term experiment that must be conducted for several more generations before results will be useful. During a terminal evaluation, the responses due to actual selection will be compared to responses predicted by simulating selection. In the meantime, we are focusing our efforts on identification of traits that may be related to uterine capacity. Identification of such traits would help the swine industry select for uterine capacity if the proposed model of litter size is eventually validated.

Table 1—Simulated genetic change in ovulation rate, uterine capacity, litter size, and embryo survival after 10 generations of selection

	Selection responses			
Selection criterion	Ovulation rate	Uterine capacity	Litter size	Embryo survival (x100)
Ovulation rate (OR)	4.62	-.02	1.57	-10.1
Uterine capacity (UC)	-.12	7.68	.71	5.6
Litter size (LS)	2.89	3.22	2.13	0.0
Embryo survival (ES)	-.73	2.35	-.07	3.3
ES + 11.8 x OR	3.96	2.36	2.40	-3.0
LS + .7 x OR	3.84	3.02	2.54	-1.7
UC + 2.73 x OR	4.14	3.99	2.96	-.7

Comparison of Methods of Predicting Breeding Values of Swine

John W. Keele, Rodger K. Johnson, Larry D. Young, and Thomas E. Socha[1,2]

Introduction

Efficiency of lean pork production can be increased by increasing growth rate and reducing fatness of pigs. One way of accomplishing this is by selecting parent pigs that take fewer days to reach 220 lb (DAYS) and have fewer inches of backfat (BF) than avg. However, just because a boar grows fast and is lean does not mean that his offspring will have the same traits. There are factors other than genetics that cause pigs to be different.

One way of increasing the chances of getting improved offspring is selecting parents based not only on their own trait but on an evaluation that is a weighted avg of their trait and the traits of some or all of their relatives. Evaluations differ by the types of relatives used. An evaluation that utilizes traits from full- and half-siblings in addition to the pig's trait is a sibling index (sib-index), whereas, an evaluation that utilizes traits from all known relatives is best linear unbiased prediction (BLUP). The weighting factors mentioned above are derived from genetic theory and depend on degree of relationship (i.e., ½ for full-siblings and parent with offspring and ¼ for half-siblings) and estimates of heritability (h^2) and the proportion of variance due to environmental effects common to members of the same litter. (c^2). Heritability is the proportion of variation due to the average effects of genes.

Theoretically, greater improvement in progeny would result from selection on BLUP instead of index and from selection on index instead of the phenotype (i.e., the pig's DAYS or BF). However, BLUP requires more calculations and more data storage than sib-index, so it is more expensive.

Data from Nebraska seedstock herds were used to compare phenotype, sibling index, and BLUP as evaluations by which to select pigs to be parents. The basis of comparison was the correlation between the evaluation of a parent and the average of its offspring.

Procedure

Birth records of 203,869 purebred pigs from five Hampshire, one Duroc, and six Yorkshire herds were obtained from the Nebraska SPF Swine Accrediting Agency. Pigs were born between 1960 and 1986. Numbers of records per herd ranged from 8,687 to 16,268 for Yorkshire, and from 3,417 to 10,279 for Hampshire. Number of records per breed were 28,681 for Hampshire, 100,455 for Duroc, and 74,733 for Yorkshire.

Phenotype was DAYS or BF expressed as a deviation from the avg of the pig's farrowing group. A sib-index based on the DAYS or BF of the pig and its full- and half-sib averages was computed. BLUP evaluations for parents were computed using records of animals born before the birth-yr of the progeny they were identified with. For example, for progeny born in 1980, records of siblings, ancestors, and progeny born prior to 1980 were used to compute BLUP for parents, but not the progeny born in 1980 or after. This does not influence sib-index or phenotype because only contemporary records were used in obtaining these quantities.

BLUP and sib-index were calculated with two different values for h^2 to evaluate the sensitivity of the results to the value of h^2 used. One set of values for h^2 was estimated from the data by regression of offspring on parent, and the other set was .35 for DAYS and .40 for BF. The second set of values is recommended by the National Swine Improvement Federation (NSIF). The value for c^2 was held constant at .05 for all analyses.

Correlations among evaluations for parents were calculated to assess the similarity between evaluations. The correlation between the evaluation of a sire or dam and the avg of its progeny was calculated as a basis by which to compare methods.

Results

Estimates of h^2 for DAYS were 11% for Hampshire, 25% for Duroc, and 22% for Yorkshire. Estimates of h^2 for BF were 16% for Hampshire, 22% for Duroc, and 10% for Yorkshire. These values are all lower than the value recommended by the NSIF.

Correlations among evaluations of sires or dams adjusted for selection on the phenotype are given in Table 1. The high correlations between phenotype and sib-index indicate agreement between these evaluations. This means that selecting pigs based on either sib-index or phenotype would yield almost the same group of selected pigs. On the other hand, BLUP was quite different from sib-index and phenotype, and was slightly more similar to sib-index than phenotype. Therefore, selection of pigs based on BLUP would yield a different group of selected pigs than selection based on sib-index or phenotype. Increasing the value of h^2 to the NSIF value instead of the estimated value for index and BLUP made the evaluations more similar.

Correlations between the avg of offspring and evaluation of parent adjusted for selection on the phenotype are given in Table 2. In light of the high correlation between phenotype and sib-index, it was no surprise that the correlation between progeny avg and evaluation of parent were similar whether the evaluation was sib-index or phenotype. The lack of advantage of sib-index over phenotype could be due to selection, small contemporary groups, or chance fluctuations. The correlation of progeny avg with evaluation of parent was similar for h^2 estimated from the data or the NSIF value. Pooled across breed and assuming the NSIF h^2, the correlation of progeny avg with BLUP of sire was 33% higher for DAYS and 44% higher for BF than the correlation of progeny avg with phenotype of sire. The advantage of BLUP over phenotype was less for dams than for sires. Pooled across breed and assuming the NSIF h^2, the correlation of progeny avg with BLUP of dam was 25% higher for DAYS and 18% higher for BF than the correlation of progeny avg with phenotype of dam. Within-breed correlations of progeny avg with evaluation of parent were larger for BLUP than phenotype or sib-index in all cases except for BF for Yorkshire, where BLUP and phenotypic deviation were equal. Coincidentally, this was also the only case in which there was an effect of heritability value used in computing BLUP or index on the correlation of progeny avg with evaluation of parent.

Differences among methods when young pigs are the only candidates for selection would not be as large as were observed in the current study. Other research has observed a greater advantage for selection on BLUP instead of selection on phenotype when all pigs in the herd were candidates for selection instead of a program where only young pigs were candidates for selection and a fixed proportion of sows and boars were culled every yr. One of the major advantages of

[1]Keele is a research animal scientist, Production Systems Unit, MARC; Johnson is a professor of animal science, University of Nebraska-Lincoln; Young is a research geneticist, Genetics and Breeding Unit, MARC; and Socha is the geneticist in charge of records processing for the Nebraska Swine Accrediting Agency, Lincoln.

[2]Details of this work are found in the J. of Anim. Sci. 66:3040-3048, 1988.

BLUP over phenotype or index for within-herd selection is in the comparison of young unproven animals to older proven animals.

Response would be greater from selection using BLUP than from selection using sib-index or phenotype. The advantage of BLUP over phenotype or sib-index would be greater for selection of sires than for selection of dams. There was no evidence that sib-index was more accurate than phenotype. This is in contrast to expectation based on genetic theory.

Quantitative genetics theory suggests that the correlation of BLUP of a parent with its progeny avg is higher than the correlation of phenotype of a parent with its progeny avg if 1) h^2 and c^2 are known without error, 2) all relationships between animals are known, and 3) the records upon which previous selection was based are included in the analysis. Some causes of pre-test selection in the populations of the current study are: 1) sale of pigs prior to completion of the test, 2) failure to probe small pigs, and 3) castration of small or unsound pigs prior to the test. The records upon which pre-test selection was based were not included in the present analyses. These results indicate: 1) the differences in accuracy among BLUP, index, and phenotype are quite insensitive to the value of h^2 used in computing BLUP or index, and 2) BLUP is more highly correlated with progeny avg than sib index or phenotype even when we know that some pedigree information was missing and that some pre-test selection occurred.

Table 1—Correlations among different evaluations on sires and dams

Breed	Estimated heritability			NSIF heritability		
	Phenotype-index	Phenotype-BLUP	Index-BLUP	Phenotype-index	Phenotype-BLUP	Index-BLUP
	Sires (Days to 220 lb)					
Hampshire	.91	.39	.56	.97	.67	.74
Duroc	.94	.62	.65	.96	.67	.69
Yorkshire	.96	.69	.71	.98	.78	.79
Pooled	.95	.64	.67	.96	.70	.72
	Dams (Days to 220 lb)					
Hampshire	.84	.53	.66	.94	.76	.79
Duroc	.90	.76	.81	.93	.81	.84
Yorkshire	.89	.63	.69	.93	.73	.76
Pooled	.88	.69	.76	.93	.78	.81
	Sires (Backfat)					
Hampshire	.87	.58	.72	.95	.72	.80
Duroc	.91	.61	.70	.95	.72	.78
Yorkshire	.82	.62	.58	.93	.81	.77
Pooled	.89	.60	.68	.95	.72	.76
	Dams (Backfat)					
Hampshire	.84	.64	.69	.93	.78	.80
Duroc	.85	.67	.75	.92	.80	.84
Yorkshire	.77	.55	.63	.92	.75	.77
Pooled	.79	.62	.72	.92	.78	.81

Table 2—Correlations of average phenotype of offspring with evaluation of sire or dam

Breed	Estimated heritability			NSIF heritability		
	Phenotype	Index	BLUP	Phenotype	Index	BLUP
	Sires (Days to 220 lb)					
Hampshire	.22	.24	.32	.22	.23	.31
Duroc	.14	.14	.20	.14	.14	.19
Yorkshire	.09	.09	.16	.09	.09	.15
Pooled	.15	.15	.21	.15	.15	.20
	Dams (Days to 220 lb)					
Hampshire	.07	.09	.10	.07	.08	.10
Duroc	.16	.15	.19	.16	.15	.19
Yorkshire	.09	.08	.12	.09	.09	.12
Pooled	.12	.12	.15	.12	.12	.15
	Sires (Backfat)					
Hampshire	.22	.23	.25	.22	.23	.25
Duroc	.17	.19	.25	.17	.19	.25
Yorkshire	.10	.07	.13	.10	.08	.10
Pooled	.16	.18	.24	.16	.18	.23
	Dams (Backfat)					
Hampshire	.10	.10	.13	.10	.10	.12
Duroc	.12	.12	.16	.12	.12	.16
Yorkshire	.11	.08	.11	.10	.09	.10
Pooled	.11	.10	.14	.11	.11	.13

Computer Simulation of Biological Aspects of Swine Production

Dewey L. Harris, Candido Pomar-Goma, and Francis Minvielle[1]

Introduction

Simulation models are sets of mathematical equations which describe, calculate, and predict performance results for complex systems with interrelated components and entities making up the system. Simulation models in animal science have become essential because the numerous interactions within and among factors involved in animal performance (genetics, nutrition, environment, etc.) cannot be fully comprehended in a quantitative and dynamic fashion by either the human mind or by traditional experimental research. In particular, precise representation of protein growth and body composition is fundamental in swine production models to accurately evaluate the efficiency of growth and reproduction, the primary biological functions pertinent to production. On the other hand, to ensure flexibility and effective prediction in a wide range of conditions, models should be mechanistic (represent cause-and-effect relationships) rather than just empirical (simply describe associations).

It is important to represent the nature and magnitude of the variability within the herd to truly evaluate some aspects of swine production system efficiency. Because of their complexity and computer requirements, past herd models including individual animals have been restricted to specific aspects of the system. Detailed models describing the biological processes in the overall life cycle of individual pigs have never before been integrated into a fully dynamic herd model.

Objectives. The objectives of a study recently completed were:

(1) to develop a flexible computer model for the life cycle of pigs with the model able to simulate the interacting effects of nutrition, genetics, and management upon growth, body composition, and reproductive performance of individual animals, and

(2) to integrate the above individual pig model into a herd model in order to evaluate the impact of the preceding factors on within-herd variability, herd dynamics, and the efficiency of overall swine production systems.

This model can now predict the performance in swine herds for specified conditions and, thus, allow comparison of alternative situations for producing pork. The biological performance of individual animals is the primary, but not the only, contribution to the performance of the herd. Some concerns of pork production must be addressed at the herd level. This study focused on the biological aspects of swine production at the neglect of climatic, seasonal, and housing aspects. Those aspects will be added in later modeling efforts.

Methodology. The model was conceptualized to simulate these two overlapping but distinct aspects of swine systems: the overall life cycle of a single animal (individual pig model) and the dynamics of the herd (herd model).

The individual pig model is deterministic (fundamental variables determine results) and aggregated (details of lower levels are considered together) at the whole animal level. This model predicts body composition and weight of males, females, and castrates; fetal development; milk yield; and suckling pig growth. The accretion rates (rates of increase) of body DNA, protein, and lipid (fat) mass are calculated at each integration step (usually one day). Empty body water and ash are empirically related to body protein mass (PT) and protein retention, respectively.

The form of equations used to describe the potential for protein accretion in pigs was adapted from that used for other species by other researchers. Genetic effects upon protein accretion potential are accommodated according to a hypothesis relating this potential to mature protein mass. The effects of energy and protein intake on DNA and on protein accretion are also included in the model.

Both energy and protein available from the diet are used first for maintenance, second for protein growth, and finally for fat deposition. During gestation and lactation, nutrient requirements for fetal growth and milk production have priority over growth (Fig. 1). Changes in body protein and lipid (fat) mass are limited by conceptual boundaries, and the values describing these boundaries depend on the nutritional and physiological status of the sow (Fig. 2). Fetal and suckling pig growth potentials are empirically estimated. Potential milk yield is evaluated with a modified version of a previous model. Genetic effects are represented by these parameters. The effects of sow feed intake and body condition on fetal growth composition and milk yield are also considered. The composition of suckling pig growth is dependent on availability of milk and creep feed.

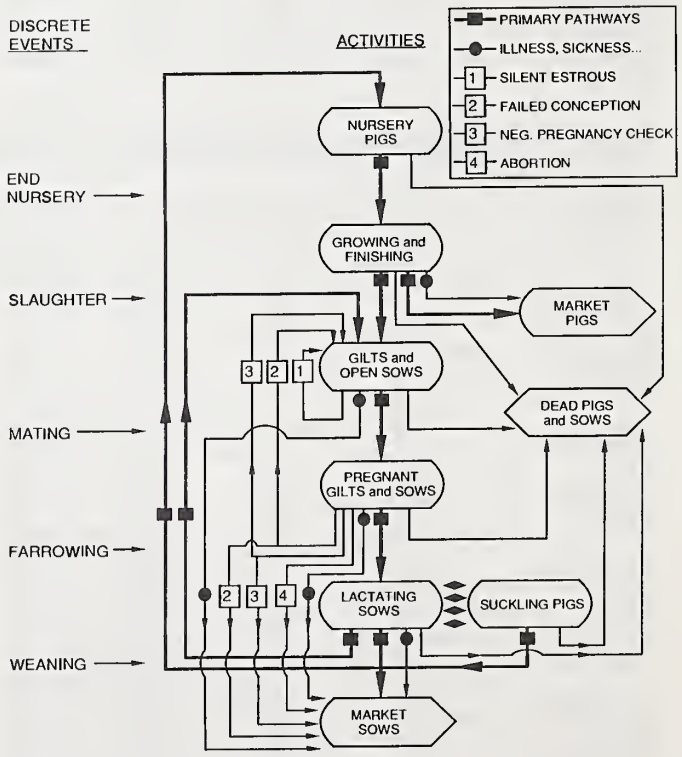

Figure 1—Energy and protein priorities for utilization.

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The herd model is discrete (handles individual animals separately) and stochastic (includes random occurrences), and each animal (suckling and growing pigs; open, gestating, or lactating gilts and sows) is individually processed over sequential simulated time using the details of the individual pig model. Herd model events are farrowing, weaning, mating, end-nursery, and slaughter. The flow of animals within the herd is shown in Figure 3. The mean and variability of the main reproduction parameters have been defined from the literature or empirically estimated. Average values for these parameters are specified according to pig genotype and then individually adjusted during simulation for the effect of the influencing factors (nutrition, parity, season, etc.). Animals within the herd are culled for any of the following reasons: illness or injury, death, delayed puberty, conception or pregnancy failure, abortion, prolonged anestrus, and parity number. Death probability is genetically attributed and adjusted according to the physiological status of the pig. Viability of suckling pigs is corrected according to the pig body condition.

Model output. For reasons of simplicity and because the model simulates so many different aspects of swine production systems, only a few results can be presented here. Figure 4 presents an example of the output of the individual pig model. Feed intake, daily protein and fat changes, and total body wt (WT) of a single sow between third and fourth lactations are presented. Litter size was 9 and 10 at the end of these lactations, respectively. Feed intake was restricted during gestation (Fig. 4) but without limit during lactation. For this specific sow, protein accretion during gestation was only slightly affected by feed intake. However, changes in lipid accretion rate were highly influenced by feed consumed. Gestation body wt gain compensated for the wt losses during the preceding lactation.

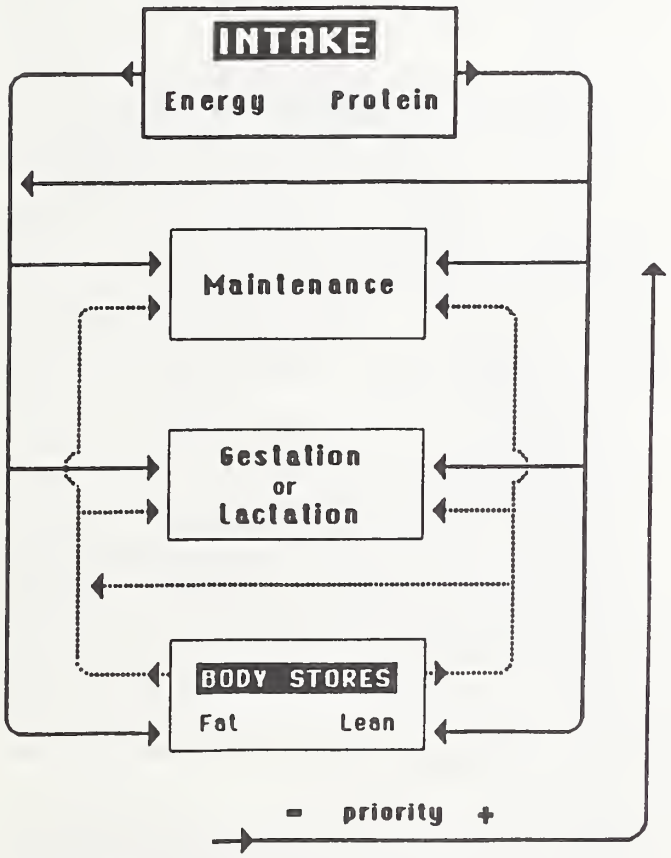

Figure 2—Protein and fat accretion (daily change) boundaries in adult animals.

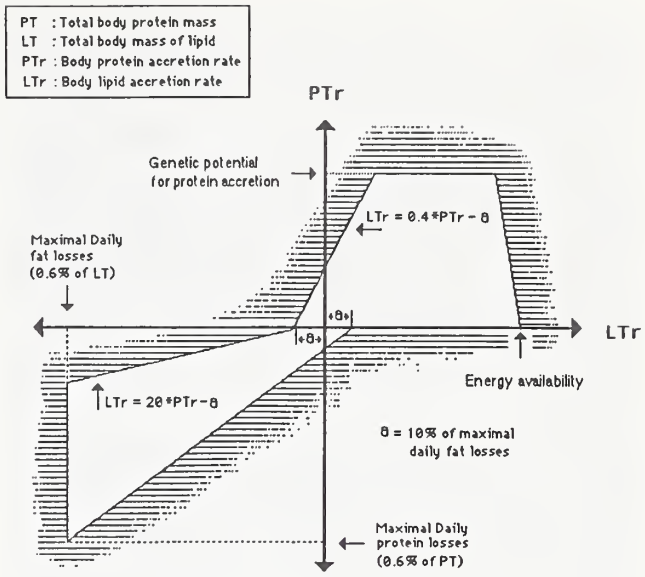

Figure 3—Animal flow through activities (stages of life cycle) and animal events.

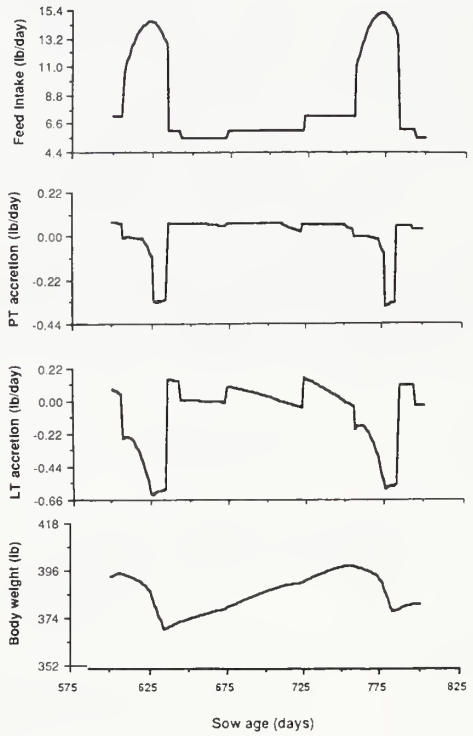

Figure 4—Daily feed intake, protein and fat accretion rates, and total body weight for a single sow.

An example of output from the herd model is shown in Figures 5 to 7. In this example, the initial number of adult females in the herd was 50. The maximum number of adult females was set at 250 and replacement gilts were chosen from the youngest females reaching 220 lb body wt in the herd. Herd inventory for the number of gestating, lactating, and total adult females is shown in Figure 5.

Results shown in Figures 6 and 7 were collected after herd stabilization. These figures show the model's ability to simulate both the mean and variation of herd characteristics. Feed intake allowed during all gestations is shown in Figure 4. The wt gain observed in first cycles (Fig. 7) is associated with the sows' gains of protein and lipid mass. In later cycles, sows do not lose significant amounts of protein, and protein gains during gestation usually compensate for these losses. Also, rate of protein retention decreases as protein mass approaches the genetic protein mass at maturity. On the other hand, fat losses in later cycles decrease as the sows get older. Feeding gestating sows independent of their age, wt, or parity, in effect, penalizes old sows because of their greater maintenance requirements. These results show the model's capability of evaluating feeding strategy effects on the sows' body conditions.

Discussion. The results presented here indicate the ability of the model to simulate growth and body composition of individual pigs, simulate herd dynamics, and provide both avg and dispersion measurements of several herd characteristics. Other results show the model's capability for accurately simulating growth and body composition of growing pigs and sows, sows' milk yield, fetal development, and suckling pig growth under several dietary regimens and management conditions.

The characterization of the genetic differences in protein mass at maturity is not complete. Appropriate data for each specific genotype would allow more accurate simulations of these differences. Part of the differences observed between simulated and real animals are probably explained by this incompleteness of the model. Environmental factors of climate, season, and housing, not included in this model, may also be responsible for some of the discrepancies. Thus, genetic calibration and extension of the model to include these considerations will be of high priority for this area of research in the future. Please note another article in this report where the plans and intentions for this area of research are explained.

Because of the complexity of the model, more calibration, validation, and sensitivity analyses are needed to determine and refine sensitive aspects of the model requiring better mathematical representation. In fact, the authors recognize that model building usually is a repetitive process, and model improvement is expected to continue for some time to come.

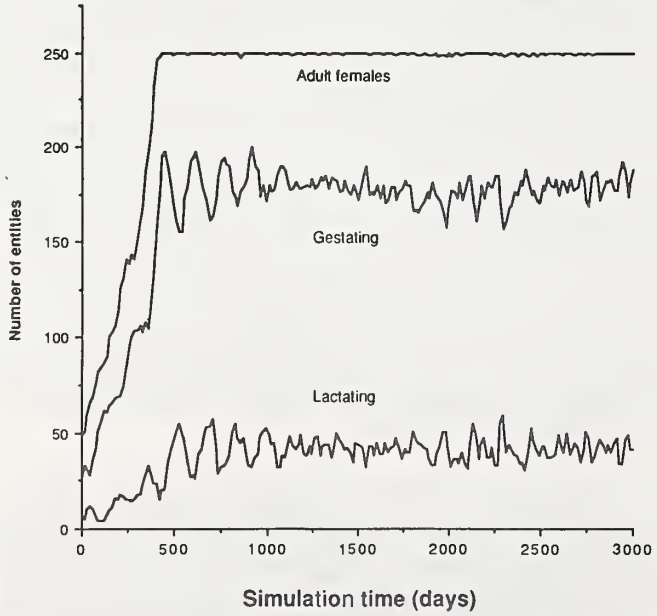

Figure 5—Number of gestating, lactating, and total adult females in the herd.

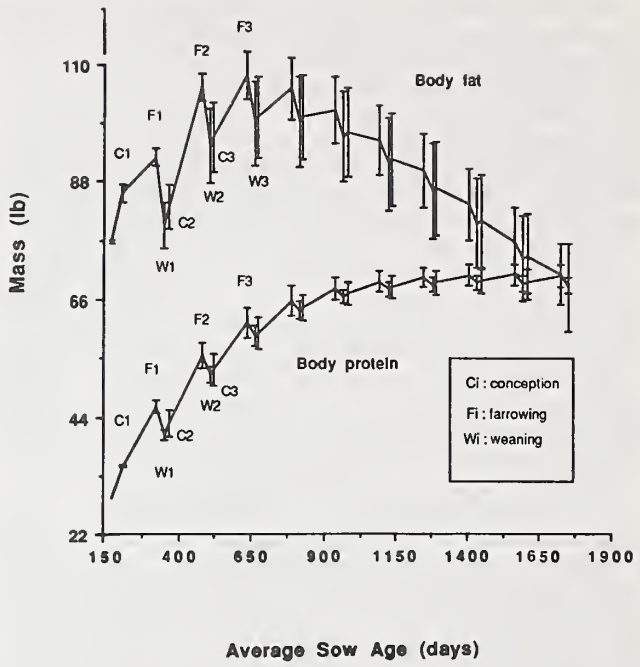

Figure 6—Averages and deviations of body protein and lipid mass of herd sows according to their average age.

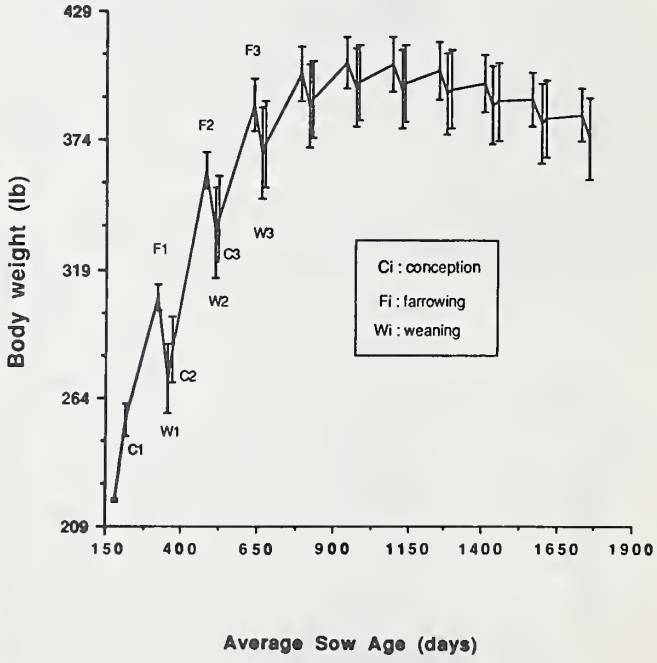

Figure 7—Averages and deviations of live body weight of herd sows according to their average age.

STAGES—A National Genetic Improvement Program for Swine

Dewey L. Harris, Donna L. Lofgren, Allan P. Schinckel, Terry S. Stewart, and Mark Einstein[1]

Introduction

The pork industry has undergone dramatic changes in the past few years. Pork producers have become aware of their production costs and measures of production efficiency, including feed conversion, litter size, pigs weaned per sow per year, and days to market. Emphasis on carcass quality has increased as packers have initiated purchase programs based on estimated carcass value.

Genetic improvement of purebred swine herds can lead the way to more efficient pork production and improve pork's competitiveness with other protein sources. At first glance, successful animal breeding programs may seem quite different; however, closer examination shows four common features. These are:

(1) Reliable data recording procedures,
(2) Data analysis and genetic evaluation procedures,
(3) Consistent selection of purebred breeding stock toward commercially relevant objectives (combination of traits),
(4) Procedures for disseminating genetic improvement from selected purebred lines into commercial production.

Successful swine breeding programs will result from the development and implementation of these four features. The development of a national Swine Testing & Genetic Evaluation System (STAGES) was a joint project between Purdue University, the Agricultural Research Service, USDA Extension Service, National Association of Swine Records, the purebred associations, and the National Pork Producers Council. STAGES computer programs have been implemented on computers servicing the eight national breed associations.

Procedure

The development of STAGES involved six steps:

STAGE 1—Within-herd genetic evaluation for postweaning growth (avg daily gain or days to 230 lb) and backfat thickness for a single contemporary group.

STAGE 2—Genetic evaluation of postweaning traits for multiple contemporary groups.

STAGE 3—A sow productivity program that includes information from relatives to evaluate gilts and boars and their parents and dams. STAGE 3 increases the accuracy of selection for litter size and litter weight.

STAGE 4—Expanded analysis of postweaning traits with an option for individual feed conversion data to allow inclusion of central test data.

STAGE 5—Reproductive and postweaning traits are combined into comprehensive indexes. Three alternative indexes are calculated: maternal, general, and terminal sire. The maternal index places greater emphasis on reproductive performance than the other indexes, and the terminal sire index emphasizes postweaning performance.

STAGE 6—Across-herd sire evaluation for reproduction and postweaning traits has been developed. This will allow for the identification of top sires within each breed for each trait or index value. The across-herd evaluation will require performance records collected over a period of two or more years in groups of herds whose owners buy boars from or sell boars to each other.

What STAGES is and does. STAGES is a series of computer programs that analyzes performance data on individual animals and their relatives to maximize the correlation between genetic merit estimates and true genetic merit.

STAGES has been implemented by all eight major U.S. breed societies. Their members collect performance data, (first feature of the Introduction); submit the records to the breed society computers, where the computers analyze and return reports (second feature) to guide their decision-making; then they select their replacement breeding stock (third feature). The breed associations provide this data processing service to members as a powerful tool to make their members' efforts more effective in genetically improving their herds and the breed. In addition, STAGES genetic evaluations guide the breeders as they price breeding stock they offer for sale to their customers (either other breeders or the commercial pork producers of the country). Thus, STAGES is expected to become the cornerstone for the purebred swine industry, achieving genetic improvement and merchandising that improvement through the marketplace (fourth feature) to improve the efficiency of pork production for the mutual benefit of the breeder, the producer, and the consumer.

STAGES expresses genetic merit estimates as expected progeny differences (EPDs). EPD is equal to one-half the breeding value of either sires, dams, or progeny. The EPD measures effects of the genes an animal is expected to transmit to his/her offspring, and estimates how future progeny of the sire (or dam) are expected to perform relative to the avg performance of the contemporary group.

Progeny deviations predict future progeny performance from performance records currently available. EPDs will deviate more from the avg as additional records are included. Deviations can be either plus or minus; for example, a boar with an EPD of -3.0 for days to market would be expected to sire offspring that reach 230 lb three days faster than the avg boar.

EPDs are directly comparable even though the numbers of records are different. This allows the seedstock producer to compare young performance- tested boars with older progeny-tested sires and young replacement gilts with older sows.

Performance data collection, analysis, and output. To participate in STAGES, the purebred producer collects basic performance information and submits it to his breed association for analysis. Only four measurements are required: (1) days to 230 lb or avg daily gain, (2) backfat thickness, (3) litter size, and (4) 21-day litter weight.

Complete herd testing is very important. Each individual will be more accurately evaluated with complete herd testing through the accumulation of additional information on relatives and larger contemporary group sizes.

Once the performance information is submitted, STAGES programs adjust the data for fixed effects (e.g., sex, age, parity, wt), calculate contemporary-group avg, identify data from relatives, and combine each individual's performance data with those from relatives, including those in previous contemporary groups, to calculate the EPDs and indexes. The resulting output forms give a complete summary of the performance of each animal, its EPDs, and index values.

[1]Harris is a research geneticist, Production Systems Unit, MARC; Lofgren is a postdoctoral research associate, Purdue University; Schinckel and Stewart are associate professors, Purdue University; and Einstein is a research associate, Purdue University.

Review of genetic principles. To understand the advantage of using this genetic tool, it is necessary to review how genetic progress is made. The most useful format to describe the amount of genetic improvement per yr is: Genetic improvement = (G i r)/G.I., where G = the genetic standard deviation, i = selection intensity, r = accuracy of selection, and G.I. = generation interval.

The genetic standard deviation (G), a measure of the genetic variation within a herd, can only be changed a small amount.

The intensity of selection (i) is a measure of the superiority of the selected individuals. As fewer of the very top animals for a particular trait or combination of traits (index) are saved for breeding, the selection intensity increases.

Selection decisions are more critical as the selection intensity increases. The greatest intensity of selection occurs in the selection of young replacement boars from the top 1 to 5% of the herd; second most important is the selection of replacement gilts. Thus, genetic merit of the young boars and gilts must be accurately evaluated.

The third term in the formula is the accuracy of selection (r). Accuracy of selection can be improved through more complete analysis of the data by the use of genetic evaluation programs that utilize the performance of relatives and adjust for non-genetic differences.

Generation interval is the avg age of parents at the birth of their offspring. Generation interval can range from one yr (all gilt litters) to more than three yr. The genetic merit estimates must be calculated in such a way that herds operating under a short generation interval (1.50 yr or less) can maximize the accuracy of selection with the records that are available.

Results

Genetic evaluation programs. Genetic evaluation programs are especially useful to improve reproduction traits with low heritabilities, such as number born alive and 21-day litter wt. Genetic evaluation programs can more than double the annual rate of genetic progress for reproductive traits. Despite the low heritability for litter size, high rates of genetic improvement are predicted. Selection schemes with rapid generation turnover have predicted rates of genetic change up to one-half pig per yr.

Genetic evaluation programs also improve the accuracy of selection for growth rate and backfat thickness. If an individual has four littermates and 20 half-sibs by the same sire, accuracy of selection increases 18% for days to 230 lb and 10% for backfat probe (Table 1). Genetic evaluation programs can also utilize available ancestral information, including the sire's and dam's performance and that of their relatives.

Increased accuracy of selection for growth rate and backfat will also improve the rate of genetic progress for feed efficiency. The relative rate of improvement for feed efficiency based on EPDs as compared with individual records is approximately 0.7 times the relative accuracy for days to 230 lb plus 0.3 times the relative accuracy for backfat. For example, if individuals in a herd avg 4 littermates and 40 half-sibs, relative rates of improvement of 26, 13, and 22% for days to 230 lb, backfat thickness, and feed efficiency, respectively, would be expected.

Using genetic evaluation programs. Seedstock producers who collect accurate, complete performance records and base their selection decisions primarily on genetic merit estimates will make consistent genetic progress toward improved commercial production efficiency. If a seedstock producer ignores genetic merit estimates when making selection decisions (using the analysis for sale or promotion only), very little, if any, consistent genetic progress will occur.

For STAGES participants to make consistent genetic progress, they must also use a high percentage of superior tested boars from other STAGES participants. If a seedstock producer purchases boars without STAGES analyses, his efforts at improvement will be diminished by the introduction of unimproved stock.

Genetic evaluation programs are honest—they don't lie, exaggerate, or mislead when accurate records have been submitted. Many highly promoted sires—boars purchased at high prices based on physical characteristics—will have below avg genetic merit estimates.

Economic impact. Genetic progress within seedstock herds is additive, accumulating from one generation to the next, when consistent selection criteria are used. It has been estimated that selecting the top 5% of boars and 25% of gilts based on the STAGES general-purpose selection index and maintaining a short generation interval could result in an annual profit potential improvement of $1.88 per hog. In practice, genetic selection programs do not realize 100% of their genetic potential. Some selection must be based on structural soundness and underlines, and matings will be planned to avoid a build-up of inbreeding. Conservatively, a seedstock herd should realize at least 50% of the potential genetic improvement, i.e., 94 cents per hog per yr. While this may not seem particularly large, keep in mind that annual improvement accumulates within seedstock herds and is disseminated to many commercial pigs.

Table 1—Relative accuracy of selection for days to 230 lb and backfat probe with differing amounts of available information[a]

	Days to 230 lb		Backfat thickness	
Available information	Accuracy	Rel. acc.	Accuracy	Rel. acc.
Individual	0.50	100	0.63	100
Individual + 4 littermates + 20 HS	0.59	118	0.69	110
Individual + 4 littermates + 40 HS + sire and dam performance	0.63	126	0.71	113
Individual + 4 littermates, 4 FS, 100 HS + sire and dam performance	0.66	132	0.73	115

[a]Calculations based on heritabilities of 0.25 for days to 230 lb and 0.40 for backfat probe. A common environmental correlation among littermates (C^2) of 0.10 was used.

Table 2 shows the expected genetic merit of seedstock and commercial herds when selection in the seedstock herd is based on the general index. The annual rate of genetic progress expected for the first ten yr (6.7 generations) is 94 cents per hog. After ten yr of such selection, the hogs produced would be expected to be born in larger, heavier litters (0.8 additional pigs and 7 lb heavier litters, at 21 days) and to have 0.10 inch less backfat, require 0.24 lb less feed per lb of gain, and reach market wt 12 days sooner than unselected hogs. Assuming the annual rate of genetic progress decreased between yr 10 and 15 to 60 cents per hog, after 15 yr of selection, the pigs produced would be expected to be born in litters one pig larger and 9.2 lb heavier at 21 days than unselected litters. They would also be expected to have 0.16 inch less backfat, to require 0.32 lb less feed per lb of gain, and to reach market wt 15.2 days sooner than unselected hogs.

Table 2—Profit potential for commercial producers when selection occurs within seedstock herds

Yr	Seedstock herd levels[a] value at the start and end of each yr	Avg level	Commercial herd level[b]	Dollar value[c]
0	0	0	0	0
1	0.00- 0.94	.47	.00	0
2	0.94- 1.88	1.41	.235	23,500
3	1.88- 2.82	2.35	.822	82,200
4	2.82- 3.76	3.29	1.58	158,000
5	3.76- 4.70	4.23	2.44	244,000
6	4.70- 5.64	5.17	3.33	333,000
7	5.64- 6.58	6.11	4.25	425,000
8	6.58- 7.52	7.05	5.18	518,000
9	7.52- 8.46	7.99	6.11	611,000
10	8.46- 9.40	8.93	7.05	705,000
	Cumulative subtotal for yr 0 to 10 =			$3,099,700
11	9.40-10.00	9.70	7.99	799,000
12	10.00-10.60	10.30	8.84	844,000
13	10.60-11.20	10.90	9.57	957,000
14	11.20-11.80	11.50	10.24	1,024,000
15	11.80-12.40	12.10	10.87	1,087,000
	Cumulative subtotal for yr 0 to 15 =			$7,850,700

[a]The seedstock herd improves at an annual rate of 94 cents from yr 1 to 10 and 60 cents from yr 11 to 15. These values are approximately one-half that expected if selection were based totally on the index.

[b]The commercial herd profit difference per hog is equal to the avg genetic level of the boars purchased and home-raised replacement gilts from the previous yr.

[c]Value of the seedstock producer's genetic selection program in improving the profit potential of commercial hogs produced by his boar purchasers each year. This value assumes the seedstock producer sells 200 boars per yr with 500 offspring per boar (100,000 total offspring per yr).

The genetic merit of commercial herds will parallel the genetic improvement within seedstock herds. Assuming a purebred producer sells 200 boars per yr, each having 500 commercial offspring (100,000 total descendants), the cumulative value of the selection program to commercial pork producers is substantial (Table 2). After 10 yr, the expected increase in profit to commercial producers is $3.1 million. After 15 yr, the increase in value of the commercial hogs is estimated to be approximately $7.8 million. With more than 85 million market hogs produced each yr in the U.S., total returns to swine selection programs could exceed $2.6 billion after 10 yr and $6.6 billion after 15 yr. The dollar return per dollar testing cost is 69.8 after 10 yr and 116.3 after 15 yr.

Industry inpact. Commercial swine producers will ultimately determine the success of swine selection programs—they will do so by making their purchase decisions based on accurate genetic evaluations. Pork producers should be willing to pay a premium for genetically improved seedstock only because of the increased value of the commercial progeny, and this will, in turn, more than offset the seedstock producer's performance testing costs.

The extent to which purebred producers utilize STAGES will be a key factor in determining their future. Competitive, profit-oriented commercial producers are looking for reliable sources of consistently superior seedstock to improve their production efficiency. Participation in STAGES will indicate each purebred producer's seriousness to meet the growing demand for superior seedstock.

Development of these computer programs has facilitated the incorporation of considerable knowledge from 50 yr of swine breeding research conducted at several federal and state research institutions. This knowledge was incorporated into a form useful to a key subindustry—breeding—that will impact the pork production industry and thus will benefit the consumers of that product.

Computerized Decision Support for Pork Production

Dewey L. Harris[1]

Introduction

Not too many decades ago, "raising pigs" was primarily a subsidiary farm activity that took place in mud lots with minimal shelter to utilize garbage and leftover grains to produce meat for the farm family. From these origins, "pork production" has evolved to be a primary enterprise on specialized farms to convert processed feedstuffs and breeding stock resources into marketable pork products. This modern production often occurs in insulated, ventilated confinement facilities with automatic feed delivery and manure disposal. This requires labor competent to care for the stock and operate the equipment and is supervised by managers with considerable expertise.

During the same decades, many industries concerned with manufacturing products from raw materials and other resources, supported by facilities and equipment and operated by labor and management, have evolved to use computerization to make the labor and management more effective and the processes more efficient. Increasingly, computers and computer software extend the capabilities of management and labor. One tool used to aid the development of plans in many manufacturing industries is simulation modeling of production system alternatives. These simulations support decision-making termed *strategic planning*. Computerization can also be involved in day-to-day execution of plans and controlled modification of the plans appropriate as responses to specific occurrences not predicted in the plan. The latter use of computers to aid decision-making can be termed *tactical control*.

The discussion in the above two paragraphs prompts us to ask a question: To what degree can computers and computer software be used to plan and control the processes involved in pork production? Computers have been used in the feed manufacturing allied industry for formulating rations that satisfy specified nutrient requirements for minimal costs from ingredients available for specified current prices. In addition, computerized controls of the mixing of these rations are becoming more commonplace. In another article in this report, STAGES is described as a computerized decision-support system for the breeding segment of the swine industry as it develops the breeding stock for input into the production segment of the industry.

But, what about the pork production segment of the industry, where feedstuffs and breeding stocks are converted into pork products? Can computers support the decision-making efforts of a farm manager as he *plans* the combinations of breeding stock, mating systems, rations, housing, equipment, and scheduling he needs to efficiently produce pork in response to fluctuating markets? Can computers assist this same manager as he implements those plans but needs to respond to the fluctuations of climate and season, shifts in performance due to extraneous influences, genetic variation, changes in the price of feed ingredients, fluctuations in market prices, etc.? Up to now, the manager of a swine production facility has had to make these decisions based, to a large degree, upon his observations, experience, and intuition.

The opportunity to use computers in decision-support for swine farm managers would require the ability to simulate and predict accurately the consequences of the many alternatives available to the manager at each decision. If such predictions are reliable, the decision-maker merely has to choose the alternative scenario where the simulated performance comes closest to his objective. Is it possible the computer could make such predictions more accurately than the manager's intuitive expectations based on his experience and training?

Decades of research into the biological processes of swine growth and reproduction seem adequate to provide a sound basis for developing simulation models that can be more precise and accurate and, thereby, extend the manager's decision-making abilities. In this paper, we will review a model developed at MARC, consider the process of simulation modeling, and present the goals of this research as is expected to impact decision-making in pork production.

Biological model. The preceding paper in this publication describes a computer model to simulate the biological processes involved in a herd of hogs with specific genetic characteristics consuming specified daily rations and responding in lean and fat growth, reaching sexual maturity, mating, conceiving, gestating, farrowing, and lactating. This biological model will be the cornerstone for an area of research at MARC that will ultimately provide a computerized decision-support system for the pork producer. This model is, at the same time, both complex and oversimplified. The cornerstone model already comprises a computer program, with a FORTRAN source code of over 3,000 lines, but is oversimplified in that it does not reflect the non-nutritional influences of climate, season, and housing upon these processes. Similarly, the dynamics of moving animals between types of housing with different environmental controls within the total farm facility has implications on the economics of pork production not currently reflected in the model. Research is also intended to examine the validity of the model developed in these past efforts and to adjust the model for the genetically controlled biological differences between breeds and crosses available to the pork producer. Extensions of the model are intended to rectify these deficiencies and to create a simulation model that will support the decision-making processes required of the manager of a pork-producing facility.

The simulation process. The procedure needed to develop models to simulate and evaluate numerous alternative systems and modifications of systems is much the same whether the product is automobiles or pork. The process is often organized into ten steps. These are:

1) Formulate the Problem
2) Conceptualize the Model
3) Collect the Required Data
4) Build the Model
5) Verify the Model
6) Validate the Model
7) Evaluate the Alternatives
8) Make Recommendations
9) Document (Publish)
10) Implement Improved Systems.

These steps should be carried out sequentially, but later steps need to be anticipated as the earlier steps are executed. In particular, the alternative systems to be compared in step 7 and changes in the system that might be implemented in step 10 have to be seriously anticipated during problem formulation (step 1) and model conceptualization (step 2).

Problem formulation. If a simulation model is to lead to improved decision-making, the model needs to reflect the objective of the production system. A statement of the system objective to guide our swine simulation project is as follows:

Pork production systems should *efficiently* utilize the

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resources of genetic stocks, feedstuffs, labor, facilities, and capital to produce high quality (low fat, high lean) pork and byproducts, so as to, simultaneously,

1) be profitable to the commercial producer,
2) satisfy demand for high quality meat products at a low cost for the nutritional well-being of the consumer,
3) contribute positively to the economic stability of the allied industries (breeding, construction, equipment, field crop production, feed manufacturing, marketing, and meat processing).

Thus, the problem formulation step (step 1) of the simulation process emphasizes finding ways to produce lean pork more profitably for the producer and at lower cost to the consumer as a contributing part of the overall food-production industry.

The cornerstone model for the biological processes has been developed to step 6 with some validation exercises complete and others needed. Validation exercises (step 6) are where simulated results are compared to experimental results to establish whether the model accurately predicts system performance. Those exercises done to date validated several predicted trends, but did not fully prove all aspects of the model were valid. The inadequacies suggest the need for model extensions as discussed above.

Alternatives to be evaluated (step 7) have to involve numerous combinations of breeding stock, crossbreeding systems, rations, housing characteristics, schedules for mating, weaning, ration changes, and movement between facilities.

The conceptualization (step 2) is relatively complete for additions and extensions to this model. This planning has been motivated by ideas on how the extended model can assist the decision-making manager of a swine production facility. In other words, the conceptualization of step 2 has been directed toward how the results of this research might impact pork production through the implementation (step 10) of new practices for swine production.

Conceptualization of Implementation. To present the goals and intentions of this area of research at MARC, we will project our conceptualization (step 2) of how, at some time in the not-too-distant future, say by the year 2000, a swine farm manager might use computers and computer-based simulation models to guide him as he makes decisions to implement improved systems (step 10). Thus, we are anticipating how the results of this research might impact and improve pork production both in strategic planning and tactical control.

Strategic planning. Innovative, progressive managers might implement this planning process on their own on-the-farm microcomputers. However, by the year 2000, the computer-guided strategic planning will more often be done on microcomputers in the offices of a swine management consultant; either a consultant who advises the manager for a fee, a public-supported swine extension specialist, or a service manager for a feedmill, a breeding stock supplier, or a pork processing plant with whom the producer has a contract.

The local microcomputer (in the farm manager's office or in the office of his management consultant) may not do the "number-crunching" calculations for the simulations. That might be done at a centralized larger computer with the local computer transmitting instructions over the telephone for new alternatives to be evaluated and compared. The larger centralized computer would execute the simulations that predict numerous details of the biology, physical movement, and economic implications of these alternatives for the producer's farm for a time period into the future. Results will be transmitted back to the microcomputer for display to the manager.

However, as a preferable alternative to tables and tables of numbers summarizing simulation results, most of the results will be presented in a graphical form on the microcomputer display screen. A special form of graphics termed "animation" will likely be used to present the results of the expected farm operation with 1 sec of time on the display representing 1 day in the operation of the farm; thus, a prediction of activities and performance for 1 yr into the future of the farm can be observed in about 6 min. However, this animated view may be interrupted, zoomed in to a part of the view, restarted at any point in simulated time, and replayed at a different speed so the viewer can dynamically study all parts of the simulated system. This can be done in a manner where both the details of the system and the interrelationships between these details can be carefully scrutinized.

However, other summaries will be displayed in static bar charts or graphs of feed consumption and composition relative to time, growth, and body compositions relative to time and facility inventory and utilization charts.

Even though the calculations probably will be done on a centralized computer, the simulations will have to be tailored to each manager's specific housing configuration and characteristics, his expected climate and seasonal cycles of weather conditions, and, perhaps, the specific breeding stock he now has. Table 1 summarizes specific characteristics of the manager's resources to be established in the computer to make the simulation unique for that manager. Many of these characteristics interact with other factors that might be strategically changed to improve the production system. These other factors are summarized in Table 2 and include nutritional characteristics of the feeds plus management schedules for ration changes and movement between facilities. In some cases, the alternatives to be simulated and evaluated should include changes in breeding stock or crossbreeding system and modifications of, or additions to, current housing facilities.

A simplistic view would be that the producer-manager is only interested in finding the system that maximizes profitability, as reflected in an economic function such as "discounted net returns for a fixed time period per unit of initial investment." However, he needs to comprehend the impact of differences

Table 1—Specific characteristics of a pork production system that makes necessary the unique evaluation of strategic alternatives for other factors

1. Location as it determines annual expected climate and seasonal cycles, especially temperature and humidity and, possibly, solar radiation and wind speed.
2. Configuration of current facilities with capacities, floor space, and air space for each room or house in total farm facility.
3. Environmental control characteristics for each current housing unit as it influences temperature, humidity, and odor control and including manure handling system.
   a. Insulation
   b. Ventilation
   c. Supplemental heat
   d. Evaporative cooling
   e. Manure handling
   f. Type of floor
4. If breeds and crossbreeding system have already been chosen, expected performance characteristics for the following traits of production animals.
   a. Maximum protein accretion
   b. Minimal fat:protein ratio
   c. Maximum protein mass
   d. Age at puberty
   e. Appetite
   f. Expected litter size at birth
   g. Expected birth weight
   h. Peak milk yield
   i. Expected weaning weight

in more fundamental performance measures in order to intelligently continue the search through the multitude of alternatives. This calls for presentation of additional relevant descriptions of the system performance in graphic and animated form as described above.

Because of the specificity of the facilities of each producer and because climatic and seasonal factors differ widely, there is not just one "best" pork production system; thus, the need is to do the simulations specific for those unique conditions. On the other hand, when all combinations of rations, breeding stock, crossbreeding systems, scheduling of weaning, mating, ration changes, moving between buildings, etc., are considered, the number of alternatives possible make it overwhelmingly prohibitive to simulate all possible sets of alternatives for each and every producer.

Thus, there will be a need for comprehensive simulation studies to establish guidelines to aid the manager in both deciding whether his system can be improved and what changes and combination of changes need to be considered. The rules-of-thumb developed from comprehensive studies of alternatives for representative situations can be presented to the manager in the form of another set of computer software termed a "model-based knowledge system." However, it is not expected that a "model-based knowledge system" will be quantitatively precise enough to reach specific final decisions for all details of the optimum system for each producer. Thus, the knowledge system will only be an intermediate step to narrow the choices down to a selected few to be compared by conducting simulations of each.

Tactical control. Even if simulation modeling led the design of a near optimum production system for the producer's resources, actual conditions would not always be the same as simulated. The weather may be warmer or cooler than expected. This weather characteristic will influence the internal operating temperature of each house, which in turn, influences the feed consumption of individuals in that house. If severe, the temperature can affect nutrient utilization in that house. In particular, energy utilized for maintaining a pig's body temperature, when cold conditions prevail in the facility, reduces the energy from the intake that will be deposited as fat. Due to genetic variation, pigs may consume feed, grow, and fatten differently than predicted for the specific cross. Due to variation in nutritional characteristics of feed ingredients, animal performance may differ from that predicted. However, all of these possibilities might be monitored during the execution of the production program. Table 3 lists the elements of weather, housing, feed, and animal performance which can be routinely monitored as a basis for tactical production control. Couldn't the deviations from what is predicted be used to adjust the model to give better predictions? Couldn't the simulation model be used to adjust the ration mix or amount to give performance closer to that desired? For example, if some pigs were getting too fat, as indicated by ultrasonically monitoring backfat level, couldn't adjustments be made in the ration mix and daily amount to limit further fatness to what is economically allowable in the current production and market situation?

Table 2—Characteristics that might be strategically changed for alternatives to current pork production system

1. Intended age, weight, and(or) fatness at marketing.
2. Age and(or) weight at weaning.
3. Age and(or) weight at other movements between housing units.
4. Ration composition and amount of feed allowed per animal in each housing unit.
5. If not specified in Table 1, crossbreeding system including breeds (as characterized by performance measures of Table 1).
6. Procedure for obtaining replacement breeding stock.
7. Temperature, humidity, and air movement targets for ventilation system.
8. Possible housing unit additions.
9. Possible modification of housing characteristics by adding insulation, ventilation, and cooling or heating capacity.

Table 3—Potential factors to be monitored to guide tactical changes in a pork production system

1. Weather fluctuations.
   a. Outside temperature
   b. Relative humidity
   c. Solar radiation
   d. Wind (if open housing)
2. Temperature and humidity within each housing unit.
3. Market prices and discounts.
4. Feed ingredient cost fluctuations.
5. Tests of actual nutritive value for feed ingredients (or delivered ration).
6. Feed intake of house, pen, or individual.
7. Periodic weights of individual animals.
8. Periodic ultrasonic backfat probe of individual animals (alternatively, visual condition scores).
9. Parity, age, weight of sows, and number and weight of pigs being nursed.
10. Current inventory of each house.

Discussion

The above discussion may seem conjectural, but it represents the research goals of the author as he, in collaboration with other scientists researching swine at MARC, attempts to package the results of decades of swine research into a form that, in the not-too-distant future, will support the decision-making activities of progressive, innovative pork farm managers. The primary limitation to accomplishing these goals is in describing complex physiological processes in the precise language of mathematics. The computer technology and computer software to accomplish this is not a limitation. For now, pork farm managers who are comfortable using computers directly are scarce, but that is likely to change as computer training becomes an essential part of public schools, as computer software becomes more "user friendly," and as computer service bureaus provide computer capabilities to clients. The use of information and knowledge can power the technology of computers and computer software to make this and other agricultural manufacturing processes more efficient and more effective.

Table 4—Characteristics of pork production systems that might be changed tactically to improve system performance

1. Ration composition for each housing unit, pen, or individual for both grow-finish and breeding units.
2. Ration amount for each pen or individual.
3. Target temperature through ventilation controls.
4. At movement to finishing, sort into pen groups with similar ration and amount of feed needed to support optimum performance.
5. At movement into gestation unit, sort into pen groups with similar nutrient needs due to age, weight, fatness, and stage of gestation.
6. Adjust ration mix and amount for lactating sows according to weight, fatness, number, and weight of pigs being nursed.
7. Adjust ration mix and amount for gestating gilts according to age, parity, weight, fatness, and past history.
8. Adjust ration mix and amount for each finishing pen to maximize lean growth and to reduce fat accumulation to optimum levels.
9. Market individual animals before projected cost of further weight gains exceeds value of weight gain as determined from monitored performance, ration control, ingredient costs, and projected market value.

At what level can the adjustment of rations be made—for the building, for the pen, or for the individual pig? The most common system for growing and finishing pigs in the U.S. today is full-feeding of a single ration for each building. Feed delivery systems are primarily designed for this approach because it is the simplest to automate. However, feed delivery systems are feasible that would deliver different rations to each pen. For these tactical control decisions to be computerized, an on-the-farm microcomputer might be necessary. Electronically controlled feeders can control ration allotment to individual animals. Such feeders are being used in Europe and in experimental situations to limit-feed individual gestating sows. There is no doubt that such systems could increase efficiency of lean growth by reducing fatness, and this is increasingly being demanded in the market place. The question is whether the potential improvement in market value will more than compensate for computerized feed delivery systems to control feeding to individual animals or, at least, to pens.

If daily control of feed mix and amount to each pen were practiced, the potential for performance control would be increased further if the pigs within that pen were uniform for nutrient requirements. This could be accomplished through monitoring of the growth and fatness tendencies of pigs during the growing period by periodic weighing and ultrasonic probing of backfat, and by recording of feed intake. This monitoring would allow sorting into new pen arrangements in the finishing house so that ration mix and amount could lead to maximum lean growth but control fatness. The feeding level would be chosen which provides an optimum compromise between market penalties for excess fatness and cost penalties for extending the time to market. Table 4 lists the factors which might be tactically controlled as responses to monitored performance, weather, and related conditions.

Similarly, controlled feeding can be done for female animals in the breeding herd according to monitored weights, fatness, and history of performance. Controlled feeding is currently common for gestating gilts and sows, but is usually based simply upon stage in gestation and visual condition observations. Relative to what the manager and caretaker can now do, there is a potential for considerable refinement in limiting intake. But this requires that the process be computerized with the computers controlling the feeding.

Assessment of Interrelationships Among Levels of Production Parameters and Maintenance Requirements

John A. Nienaber and Ling-Jung Koong[1]

Introduction

Evaluations of energy utilization efficiency for animal growth have often been based on partitioning energy intake between maintenance and growth or other production functions. Separation of metabolism into maintenance and production is artificial, yet useful, in practical animal production. Maintenance requirements are frequently expressed as the energy required per unit body wt to a constant power. Regardless of the value used for the power exponent, the underlying assumption is that the maintenance requirement is solely a function of body size. However, there is much evidence that many variables—such as breed, sex, diet, level of production, thermal environment, and previous nutritional history—influence estimates of maintenance energy requirements.

The purpose of these studies was to examine the changes of fasting heat production and other associated measurements in pigs to estimate maintenance requirements. Various feeding schedules and a prolonged wt maintenance period were used to demonstrate problems in the use of body wt to express maintenance requirements and to offer some possible explanation for inconsistencies found in energy use estimates.

Procedure

Four experiments were used to evaluate the effects of factors other than body wt on the maintenance requirements. Maintenance can be defined as the mimimum energy required by an animal to sustain life. This can be estimated by measuring the heat production of an animal at rest without any thermal demands (at comfortable temperature). In all four studies, the primary measure of the maintenance was fasting heat production. Measurments were taken over a 16-hr period after pigs had spent approximately 7 hr in a calorimeter chamber. Pigs were fasted 24 hr before being moved to the calorimeter for the heat production measurements, so that 30 hr had elapsed since the last meal when measurements began. This period was needed to clear all feed from the upper GI tract and to standardize the measurement. Barrows were used in all studies, and the diet was a standard growing ration of corn-soybean meal base with 16% crude protein. Each experiment also included slaughtering the pigs and weighing the stomach, small and large intestines, liver, pancreas, spleen, kidneys, and heart.

The initial experiment evaluated the impact of rate of growth or plane of nutrition on maintenance requirements. Twenty-seven 12-wk-old barrows weighing 60 lb were assigned to three treatments. One group was fed to gain 42 lb over 35 days and then to lose 11 lb during the second 35 days. The second group was fed to gain 15.5 lb during the first and second 35 days. The third group was fed to lose 11 lb during the first period and then to gain 42 lb over the second period. At the end of the study, all animals weighed 91 lb but grew at three different rates during the last 35 days of the study. Animals were then placed in the calorimeter chamber after 24-hr feed withdrawal, and their heat production was measured. Upon completion of the calorimetry, the animals were slaughtered and specific organs were weighed.

The second study used genetically lean and obese pigs as experimental units. The three different growth rate treatments were identical to the first study, with pigs beginning at 60 lb and ending at 91 lb 70 days later.

The third study involved 75-lb crossbred barrows which were fed to gain 35 lb during an initial 30-day period. Animals were then fed to maintain the 110-lb body wt for up to 66 days by adjustment of daily feed intake. As with the other experiments, animals were weighed twice weekly, and feed adjustments were made to achieve the target wt. In this study animals were removed for calorimetry and slaughter at 0, 2, 4, 8, 16, 24, 32, 47, and 66 days, after reaching target wt. Calorimetry and slaughter procedures were the same as above.

The fourth study was designed to investigate the effects of body size on the relationships found in the first three experiments. It involved 66 crossbred barrows fed to attain a body wt of 77 lb at the beginning of the experiment. Animals were then assigned to three treatments which: grew at a constant rate of 1.1 lb/day for the full 113 days; maintained constant wt for 30 days, then grew at a rate of 2.2 lb/day for 30 days, then grew at 1.1 lb/day for 53 days; or maintained constant wt for 30 days, then grew at a rate of 1.5 lb/day for 83 days. Heat production measurements were made, and those animals were slaughtered: at the beginning of the study, at the end of the 30-day constant wt period, and at target body wt of 110, 143, and 201 lb for each of the treatments. Six animals were included in each slaughter group. All animals achieved the 201 lb final wt at the same time but by three different growth rates.

Results

Table 1 is a summary of the results of the first two studies and gives the comparison of the effects of rate of growth on the maintenance requirements of crossbred and genetically lean and obese pigs. The HL, MM, and LH headings refer respectively to high-low, medium-medium, and low-high rates of growth used as treatments in the first two studies. The fasting heat production and wt of stomach, small and large intestines, pancreas, liver, and kidneys were all affected by the feeding treatments. Note that the heart and spleen were affected only by body wt. It should be noted that the size of those affected organs were directly proportional to the rate of fasting heat production. The contribution of the digestive system has been shown to be energy intensive and to account for 20 to 30% of the total heat production in pigs, sheep, and cattle. It follows that the impact of reducing the rate of feeding would be to reduce the size of the organs required to assimilate the feed within the animal. However, this is the first experimental documentation of the impact of that effect.

In order to determine the length of time needed to achieve the reduction of organ size and maintenance requirements, the third study was conducted. It was found that the effects were detected on the second day of constant body wt maintenance and that the size of organs and fasting heat production rate dropped constantly for about 3 wk, reaching stable levels approximately 20% below initial measurements. The wt of the heart, spleen, and pancreas was found to be unaffected by treatments, which was in agreement with the first studies.

Results of the fourth study showed that during the 30-day period of 77 lb constant wt there was a 17% reduction in fasting heat production and similar reductions in the wt of the liver, kidneys, stomach, large and small intestines, and pancreas.

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There was no change in the spleen or heart wt. Following this constant wt period there was no effect of feeding level between the 1.1, 1.5, and 2.2 lb/day treatments on any of the measures taken at 110 lb. However, at 144 lb, the 2.2 lb/day treatment pigs had a 22% higher fasting heat production and similarly higher organ wt for liver, kidneys, stomach, large and small intestines, and pancreas than for the 1.1 lb/day treatment. The 1.5 lb/day treatment animal measurements were also substantially higher than the 1.1 lb/day animals. The heart and spleen wt were again unaffected by treatments. At 201 lb, there were no treatment differences in any of the organ wt or the fasting heat productions.

These results confirm the importance of level of feeding and growth rate just prior to measurement, as well as the importance of genetics on the measurement of maintenance requirements. The close agreement of the fasting heat production changes and the changes in the wt of metabolically active organs is additional verification of the importance of those organs. This information helps the producer better understand the cost of growth and efficiency of growth.

Table 1—Effect of different nutritional regimens on organ sizes and fasting heat production of obese, lean, and crossbred pigs[a]

	Obese			Lean			Crossbred			
Measure	HL	MM	LH	HL	MM	LH	HL	MM	LH	Sig[b]
Final live wt, lb	90.2	91.9	87.5	88.8	92.8	91.9	90.2	90.6	89.1	
Stomach, g	231	303	332	297	338	372	263	287	338	T, L
Small intestine, g	541	685	795	629	704	806	699	853	1,013	T
Large intestine, g	432	501	537	518	640	649	451	492	588	T,L
Pancreas, g	39	60	17	52	69	75	52	63	79	T,L
Liver, g	407	549	623	454	550	616	447	537	646	T
Heart, g	138	134	138	164	163	155	165	157	155	L
Kidneys, g	99	121	138	114	134	136	112	120	139	T
Spleen, g	50	55	50	65	63	55	53	51	49	L
Fasting heat production, kcal/d	1,331	1,503	1,668	1,257	1,755	1,922	1,079	1,298	1,519	T

[a]High-low (HL), medium-medium (MM) and low-high (LH) refer to plane of nutrition. HL group was fed to gain 42 lb during the first 35 days (period 1) and to lose 11 lb during the second 35 days (period 2). MM group was fed to gain 15.5 lb during both periods 1 and 2. LH group was fed to lose 11 lb in period 1 and gain 42 lb in period 2.

[b]Statistical significance at $P<0.05$ level: T = treatment effects; L = live effects.

A Computer Model of Ovulation Rate, Uterine Capacity, Potential Viability, and Litter Size

Gary L. Bennett and Kreg A. Leymaster[1]

Introduction

Litter size is the net result of several steps in the conversion of ova into pigs at birth. These steps are expressed sequentially and may be interactive. Three important steps in this process are: (1) the shedding of ova by the sow; (2) the elimination of those ova or embryos that have genetic defects, are not fertilized, or are otherwise not viable; and (3) the elimination of embryos that exceed the uterine capacity of the sow. Uterine capacity refers to the litter size of a female when ovulation rate is very high—that is, the largest litter the female can produce.

The purpose of this research was to develop a simple computer model of litter size. The model needed to include the steps of ovulation, elimination of ova due to inviability, and elimination of embryos due to limited uterine capacity. A model including these steps should be useful for interpreting experiments where ovulation rate and litter size have been measured and for predicting the results of future experiments and production systems.

Procedure

Litter size will be less than or equal to the number of ova shed (ovulation rate), except in the rare case of identical twins. Thus, ovulation rate was used as the starting point of the computer model. Results of experimental measurements of ovulation rate were used to set the avg of ovulation rate to 12.68 ova and to set the variability in ovulation rate. The potential viability of ova and embryos was set at 82%, based on the percentage of viable ova remaining in early stages of gestation as measured in experiments.

There were no direct measurements of uterine capacity and its variability. However, the avg and variation in litter size of gilts similar to the gilts used to determine ovulation rate were known. Based on the model, it was determined that an avg of 12.0 pigs for uterine capacity would produce an avg litter size of 9.26 pigs, equal to the litter size of experimental gilts.

The computer model then consisted of the following steps:

1. Ovulation rate was randomly chosen with an avg of 12.68 ova.
2. Ovulation rate was randomly reduced by an avg of 18% to determine the number of potentially viable embryos.
3. Uterine capacity was randomly chosen with an avg of 12.0 pigs.
4. Uterine capacity was compared to the number of potentially viable embryos, and the smaller of the two values determined litter size.

Two examples are provided to illustrate the model. In the first example, an ovulation rate of 15 ova was chosen (Step 1). Three ova were determined to be inviable, leaving 12 potentially viable embryos (Step 2). A uterine capacity of ten pigs was chosen (Step 3). Litter size was set equal to 10 (Step 4), because uterine capacity (10) could not support all the potentially viable embryos (12). In the second example, an ovulation rate of ten ova was chosen (Step 1). One ovum was determined to be inviable, leaving nine potentially viable ova (Step 2). A uterine capacity of 14 pigs was chosen (Step 3). Litter size was set equal to 9 (Step 4) because all potentially viable embryos (9) could be supported by uterine capacity (14).

The model determines the relationship among ovulation rate, uterine capacity, and litter size in individual sows and gilts. However, it is also useful to know the relationships among avg ovulation rate, avg uterine capacity, and avg litter size. These relationships were determined by simulating herds of 2,000 sows with avg ovulation rates ranging from 11 to 19 ova and avg uterine capacities ranging from 11 to 19 pigs. The results of these simulations are illustrated in Figure 1. These relationships can be used to determine the benefits of changes in genetics and management through changes in litter size.

Results

The computer model of litter size and its components was able to approximate experimental relationships among different components of litter size. For example, experimental estimates of the change in litter size per one ovum increase in ovulation rate have ranged from .38 to .42 pigs per ovum, slightly less than the value of .47 that resulted from the computer model.

The computer model of litter size was also able to predict litter size in experiments where estimates of the avg ovulation rate and uterine capacity were available. In one experiment, ovulation rate averaged 11.7 ova and avg uterine capacity was estimated to be 12.2 pigs. Litter size averaged 9.0 pigs compared to 8.8 pigs predicted by the model. In another experiment, ovulation rate averaged 13.5 ova and uterine capacity was estimated to avg 10.8 pigs. These inputs to the computer model resulted in a predicted avg litter size of 9.2 pigs compared with an actual litter size of 9.4 pigs. In a third experiment, avg ovulation rate was 14.1 ova and avg uterine capacity was 13.6 pigs. Predicted litter size was 10.3 pigs and actual litter size was 10.3 pigs. In a fourth experiment, avg uterine capacity was estimated to be 10.7 pigs and avg ovulation rate was 13.4. Predicted litter size was 9.2 pigs and actual litter size was 9.8 pigs. In a second part of the fourth experiment, ovulation rate was 11.8 ova and uterine capacity was estimated to be 12.8 pigs. Predicted litter size was 9.0 pigs compared with an actual mean of 9.3 pigs. These comparisons show good agreement between predicted and actual litter size given the small number of litters in each experiment.

It is apparent from Figure 1 that large litter size requires both high ovulation rate and high uterine capacity. We expect that avg ovulation rate and avg uterine capacity are somewhat similar within a breed of swine because they have been selected for increased litter size for many generations. This reasoning suggests that most breeds would lie close to a diagonal line drawn from the lower left corner to the upper right corner of Figure 1. If this is true, it suggests that increasing ovulation rate without increasing uterine capacity or increasing uterine capacity without increasing ovulation rate will not result in a large increase in litter size.

This model, if correct, strongly suggests that a combination of increased ovulation rate and uterine capacity will be needed to dramatically increase litter size. It has already been shown that increasing only ovulation rate either by hormonal manipulation or by genetic selection results in increases of only one pig or less at birth. Ovulation rate can be determined directly in sows and gilts by the use of medical equipment to observe the ovaries. Uterine capacity is less well-defined, from a practical standpoint, and can only be determined indirectly by counting pigs at birth in dams with high ovulation rates. There is little known about what causes differences in uterine capacity. Experiments to determine how to increase uterine capacity should be done in sows and gilts with high ovulation

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rates. If uterine capacity is increased in sows with normal ovulation rate, the increase in litter size will be small and hard to detect.

The computer model predicts that some breeds and crosses will respond differently to different management practices. This should be useful for predicting how different management systems affect the efficiency of producing pork.

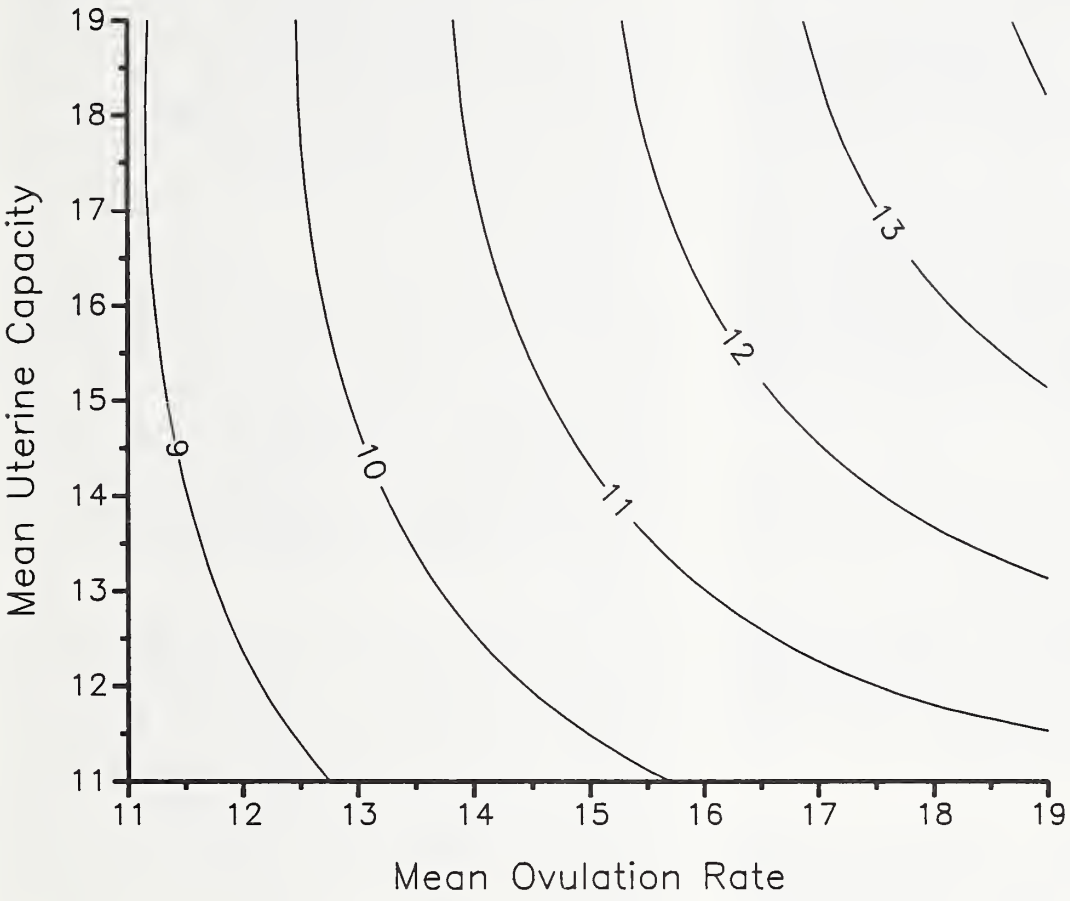

Figure 1—Contours of litter size showing the relationship of average litter size to average ovulation rate and uterine capacity.

Effects of Adrenergic Agonists and Insulin on Porcine Adipose Tissue Lipid Metabolism *In Vitro*

Dan C. Rule, Stephen B. Smith, and Harry J. Mersmann[1,2]

Introduction

Many metabolic processes in the animal body are regulated by hormones. Perhaps the most important hormones regulating synthetic and degradative pathways in adipose tissue (fat) are insulin and the adrenergic hormones (for example, adrenaline = epinephrine), respectively. In porcine adipose tissue, insulin stimulates fat synthesis in tissue slices. Insulin effectively inhibits the epinephrine-stimulated degradation of fat lipolysis. The purposes of these studies were to estimate the response of porcine adipose tissue fat synthesis to insulin; and, because adrenergic hormones may inhibit synthetic pathways in porcine adipose tissue, the effect of these hormones on fat synthesis in porcine adipose tissue slices was established. Finally, because our experience has indicated that porcine adipose tissue is somewhat refractory to stimulation of glucose oxidation and incorporation into lipids by insulin *in vitro*, and to inhibition of these metabolic processes by adrenergic hormones *in vitro*, we studied the effects of preincubation on tissue responses to these hormones.

Procedure

Adipose tissue was obtained from female and castrated male pigs weighing about 81 or 138 lb. A biopsy gun was used to obtain tissue from the dorsal neck region of anesthetized pigs. A pool of tissue slices was prepared.

Fat synthesis was measured in tissue slices or in tissue homogenates whereas fat degradation was measured in tissue slices. Synthesis was measured by following radioactive glucose (^{14}C-glucose) incorporation into lipids or by following incorporation of radioactive palmitate (^{14}C-palmitate) into lipids. Degradation of fat was followed by measuring the release of fatty acids to the incubation medium.

Results

Synthesis. The acute effect of insulin on porcine adipose tissue glucose oxidation to CO_2 or incorporation into lipids (synthesis) *in vitro* remains enigmatic. In most laboratories, insulin addition to porcine adipose tissue incubated for 2 hr *in vitro* either does not increase or produces only a modest increase in glucose incorporation into CO_2 or total lipid that usually is not dependent on insulin concentration.

We attempted to maximize insulin effects by preincubation of tissue slices for 2 hr with insulin; then, after a medium change, incubation to measure glucose carbon incorporation into CO_2 and total lipid. Insulin did not stimulate glucose carbon incorporation into CO_2 or lipid, and preincubation did not change this result (Fig. 1A).

Two epinephrine analogs (clenbuterol and cimaterol) yield increased carcass muscle mass and decreased carcass fat mass when fed to growing animals raised for meat production. These carcass changes have been observed in sheep, cattle, and chickens. Some orally administered beta-adrenergic agonists have less consistent effects on weight gain and feed intake, but in some studies there is an increase in gain or a decrease in feed intake, or both. Regardless of changes in gain or feed intake, if efficiency were calculated on the basis of the product of meat animal production (lean mass), oral norepinephrine analogs markedly improve efficiency of product yield.

Speculation on the mechanism for changes in carcass composition in response to dietary beta-adrenergic agonists revolves around observations made on muscle and adipose tissue *in vitro*. The evidence has mostly accrued from laboratory species, and there is little evidence that any of these mechanisms operate during oral administration of a beta-adrenergic agonist or that norepinephrine analogs affect the proposed anabolic or catabolic processes in tissues from the meat-producing species *in vitro*. Stimulation of beta-adrenergic receptors on adipose tissue and muscle cells would lead to increased fat degradation, decreased fat synthesis, and to increased protein synthesis and decreased protein degradation in muscle.

We have attempted to demonstrate inhibition of anabolic pathways in porcine adipose tissue *in vitro* to provide evidence for one of the possible mechanisms by which norepinephrine analogs might change porcine carcass composition *in vivo*. Incubation of porcine adipose tissue slices with isoproterenol, epinephrine, fenoterol, or clenbuterol did not inhibit glucose oxidation to CO_2 or glucose incorporation into total lipids (Fig. 1B). The lack of inhibition of anabolic function in porcine adipose tissue (Fig. 1B) was unexpected, because norepinephrine analogs inhibit lipogenesis in adipose tissue from sheep and rodents and in hepatic tissue from chickens. Pig adipose tissue seems to be different from that of some other species.

Insulin did not stimulate the incorporation of palmitate into lipids (Fig. 2). Isoproterenol, an analog of the adrenergic hormone epinephrine, did inhibit palmitate incorporation into lipids but only under specific conditions (Fig. 2).

Degradation. Previous studies have demonstrated that insulin inhibits fat degradation in porcine adipose tissue. Thus, insulin can interact with the tissue to produce metabolic effects but does not stimulate synthetic pathways very effectively in this species. Likewise, adrenaline (epinephrine) and some of its analogs stimulate fat degradation in porcine adipose tissue. Thus, the marginal inhibition of fat synthesis in porcine adipose tissue by these compounds is not the result of inability to interact with the tissue. These studies emphasize the difficulty in extrapolating laboratory results to the live animal and indicate that laboratory results should be viewed as suggestive of what might be occurring in the animal. Although laboratory studies do not always indicate exactly what is happening in the animal, they do allow us to derive approximations that could not be measured in the animal.

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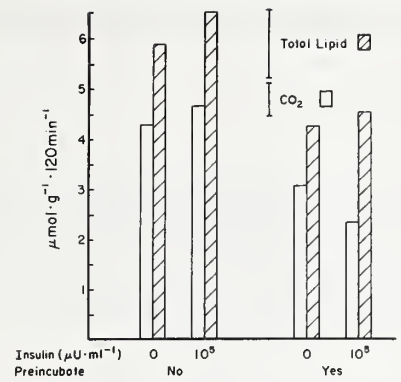
[2]The full report of this work was published in J. Anim. Sci. 65:136-149, 1987.



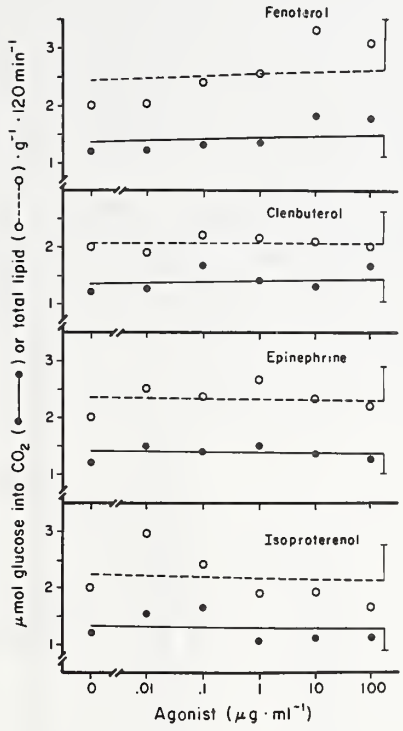


Figure 1—Hormone effects on glucose metabolism.

A. *Long preincubation with insulin.* Medium of KRB-buffer contained 2% BSA, 5.6 mM glucose, and no insulin (0) or 10^5 μU insulin/ml (4.05 μ/ml). Some tissue was preincubated (Yes) for 2 hr 98°F in the medium (without ^{14}C-glucose); some tissue was not preincubated (No). Insulin was either present during both preincubation and incubation or absent during both procedures. After preincubation, the medium was removed, the tissue was washed in .9% NaCl 98°F and then was transferred to fresh medium and incubated 2 hr 98°F with ^{14}C-glucose to measure glucose incorporation into CO_2 and total lipids. Data represent three replicate experiments, each with tissue from a different pig. There was no effect of insulin or preincubation ($P > .1$); pooled SE indicated.

B. *Adrenergic agonists.* Experiment similar to 1A except there was no preincubation, glucose concentration was 20 mM, insulin was at 10^5 μU insulin/ml (4.05 μg/ml) and there was no BSA present. Epinephrine analogs were absent (0) or present as indicated. At 100 μg/ml, isoproterenol bitartrate = 252 μM, epinephrine bitartrate = 300 μM, fenoterol x HBr = 260 μM and clenbuterol HCl = 318 μM. Closed symbols indicate incorporation into total lipids. All agonists were tested in each replicate. Vertical bars are pooled standard error for the slope. Regression analysis indicated fenoterol tended ($P < .1$) to increase CO_2 production. Hormones did not change any other rates.

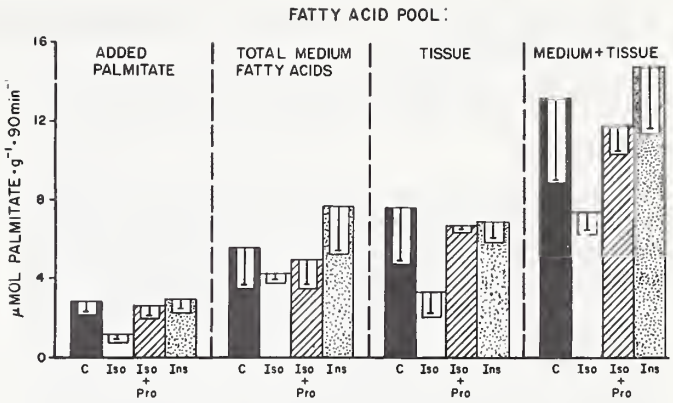


Figure 2—Hormone effects on palmitate esterification. Tissue slices were incubated for 90 min with no hormone (C), with 10^{-5} M isoproteronol (Iso), with Iso plus 10^{-5} M propranolol (Iso + Pro) or with 10^4 μU (405 ng) porcine insulin/ml (Ins). Palmitate incorporation is expressed as μmol palmitate incorporated into total lipids/g tissue/90 min and was calculated from palmitate added to medium, from total free fatty acid concentration in medium, in tissue, and in medium plus tissue. Error bars equal 1 SD for two replicate experiments, each with adipose tissue from a different pig. Isoproterenol inhibited ($P < .05$) palmitate incorporation except when incorporation was calculated from medium fatty acids.

Hormonal Control of Porcine Adipose Tissue Fatty Acid Release and Cyclic AMP Concentration

C. Y. Hu, Jan E. Novakofski, and Harry J. Mersmann[1,2]

Introduction

It is generally accepted that fat degradation or the lipolytic response of adipose tissue to a variety of hormones is mediated by a regulatory system. The initial event is hormone interaction with specific membrane receptors followed by activation of adenylate cyclase. Elevated adenylate cyclase activity increases the concentration of cyclic-AMP (cAMP), the intracellular second messenger, which activates a protein kinase that, in turn, phosphorylates and activates a triacylglycerol lipase enzyme. The lipase enzyme catalyzes the degradation of triacylglycerol to free fatty acid (FA) and glycerol.

Because many adrenaline analogs stimulate adipose tissue lipolysis in a variety of species but only a few analogs stimulate porcine adipose tissue lipolysis, it was of interest to ascertain whether the specificity in porcine adipose tissue resides in the receptor or at some other point in the activation cascade. We assessed the capacity of adrenaline analogs to elevate porcine adipose tissue cAMP concentrations to provide evidence that the specificity resides in the capacity of the coupled receptor-adenylate cyclase to produce cAMP.

Procedure

Crossbred (¼ Yorkshire, ¼ Landrace, ¼ Large White, ¼ Chester White) female pigs were raised under normal husbandry conditions and fed *ad libitum* a corn-soybean meal-based diet (16% crude protein) from 10 wk of age. The pigs (66 to 125 lb) were anesthetized with sodium thiopental, and adipose tissue biopsy samples were obtained from the dorsal neck region with a biopsy gun. A pool of tissue slices, .4 mm thick, was prepared (about 15 min after biopsy) from the biopsy samples from each pig.

To measure the degradation rate, tissue slices (100 mg total) were incubated for 120 min in buffer, glucose, and ascorbate. Basal lipolytic rates were determined in triplicate without addition of exogenous hormones. Stimulated lipolytic rates

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[2]Details of this work are published in the J. Anim. Sci. 64:1031-1037, 1987.

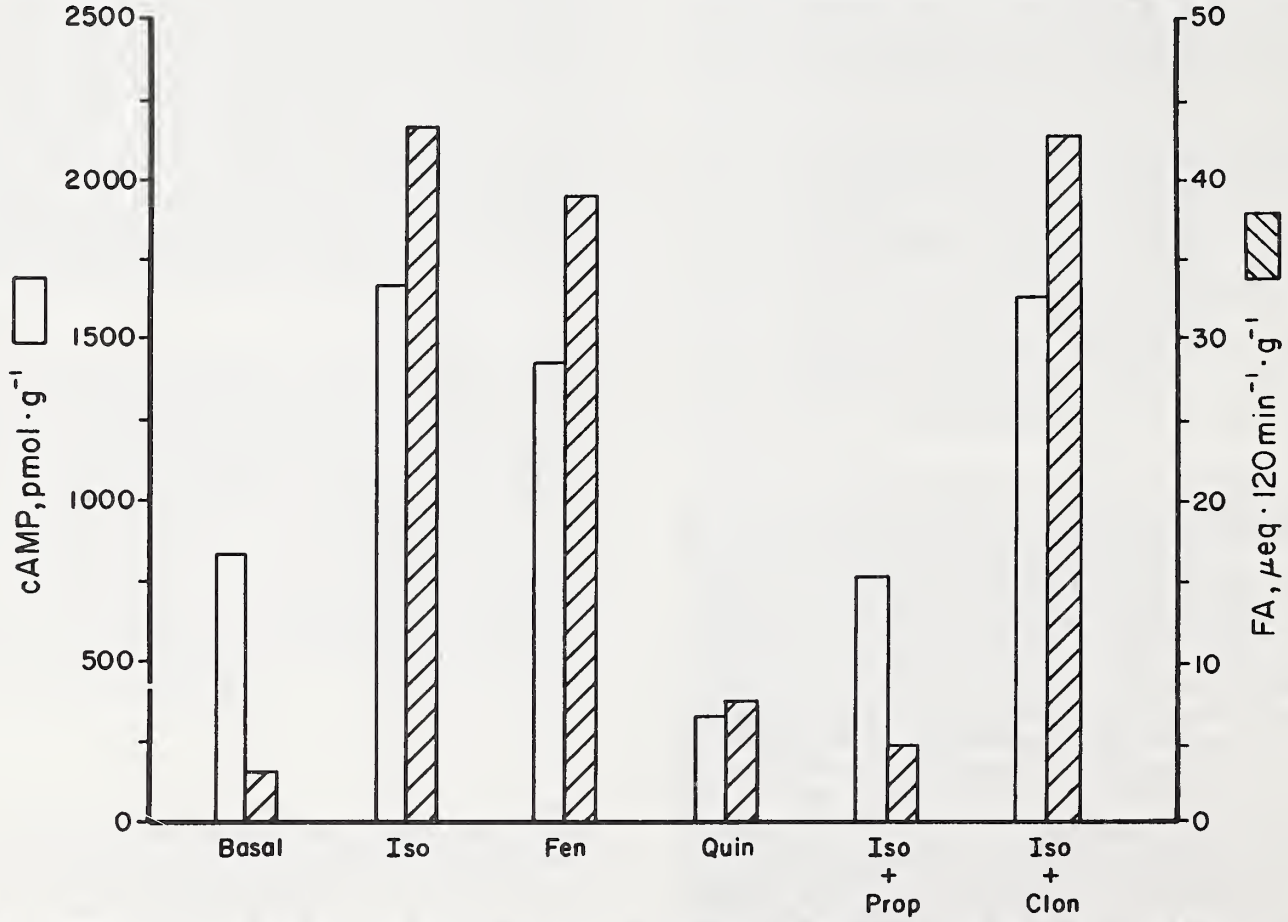

Figure 1—Effect of various lipolytic and antilipolytic agents on isoproterenol-stimulated FA release and cAMP generation. All flasks contained 10^{-3} M theophylline. (The basal flasks contained theophylline only.) Additions to flasks were 10^{-5} isoproterenol (Iso, $beta_1$ + $beta_2$-agonist); 2.6 x 10^{-4} M fenoterol (Fen, $beta_2$-agonist); 3.1 x 10^{-4} M quinterenol (Quin, $beta_2$-agonist); 3.4 x 10^{-5} M propranolol (Prop, beta-antagonist) or 3.8 x 10^{-5} M clonidine (Clon, $alpha_2$-agonist). Stimulation of FA release was greater ($P<.05$) than the basal response in the presence of Iso and Fen but not Quin. Production of cAMP was stimulated ($P<.01$) by Iso and Fen, but was lower ($P<.01$) than the basal rate for Quin. Concentrations of FA and cAMP elevated by Iso were inhibited ($P<.05$) by Prop but not by Clon. Data are means from three different experiments, each using tissue from a different pig.

were determined in triplicate in the presence of an exogenous adrenaline analog (e.g., 10^{-4} M isoproterenol) as indicated for each experiment. The degradation rate was assessed by extraction and titration of FA concentration in the medium.

To measure changes in tissue cAMP concentration, 100 mg tissue slices were incubated for 3 min at 98°F in media identical to that used to measure degradation rates, unless indicated otherwise. Tissue from an incubation flask was homogenized and assayed for cAMP.

Results

Adrenergic effectors. Previous studies indicated stringent specificity of adrenaline analogs to stimulate fat degradation by porcine adipose tissue. Selected analogs used in those studies were tested for effects on tissue cAMP concentration. Isoproterenol at 10^{-5} M stimulated the release of FA to the medium about tenfold compared with the basal condition, whereas cAMP concentration in the tissue was stimulated about twofold (Fig. 1). Fenoterol stimulated FA release to the medium to about the same extent as isoproterenol, as observed in previous studies; fenoterol also increased cAMP concentration (Fig. 1). Quinterenol was considered not active regarding lipolytic stimulation in porcine adipose tissue, because it was not possible to demonstrate a dose x response relationship. Quinterenol did not increase the release of FA to the medium in the present experiment at a single high dose. Quinterenol did not cause an increase in cAMP concentration (Fig. 1). The same specificity for these purported $beta_2$-adrenergic agonists was observed *in vivo* also, because intravenous infusion of isoproterenol and fenoterol into pigs caused an acute increase in plasma FA concentration, whereas infusion of quinterenol did not (data not indicated).

Propranolol inhibited the isoproterenol-stimulated release of FA and increase in cAMP, but clonidine did not inhibit (Fig. 1). These data indicate the specificity of inhibitors of fat degradation. Intravenous infusion of propranolol inhibited the isoproterenol-stimulated increase in plasma FA in anesthetized pigs, indicating the observations *in vitro* mimic those *in vivo* (data not indicated).

Dobutamine modestly stimulated porcine adipose tissue, and this was reflected after *in vivo* infusion by elevation of plasma FA, whereas tazolol was inactive *in vitro* and *in vivo* (data not indicated). Dobutamine stimulated FA release to the same extent as isoproterenol and elevated tissue cAMP concentration (Fig. 2). Tazolol did not elevate FA in the medium or tissue cAMP concentration (Fig. 2). Clenbuterol, another adrenaline analog, did not stimulate FA release *in vitro*, nor did it cause an increase in cAMP concentration (Fig. 2). Intravenous infusion of clenbuterol into pigs elevated plasma FA concentration, suggesting a mechanism *in vivo* other than direct interaction with adipose tissue.

Epinephrine (or adrenaline) stimulated FA release, as reported previously, and increased tissue cAMP concentration (Fig. 2). The addition of phentolamine, an inhibitor (Fig. 2), did not change FA release or tissue cAMP concentration. Similar results were observed *in vivo*; epinephrine infusion elevated plasma FA concentration, but simultaneous infusion of phentolamine did not change the epinephrine effect.

The results presented in this paper suggest that the stringent specificity observed for stimulation of swine adipose tissue fat degradation or lipolysis *in vitro* by analogs of adrenaline resides in the receptor coupled to cAMP production.

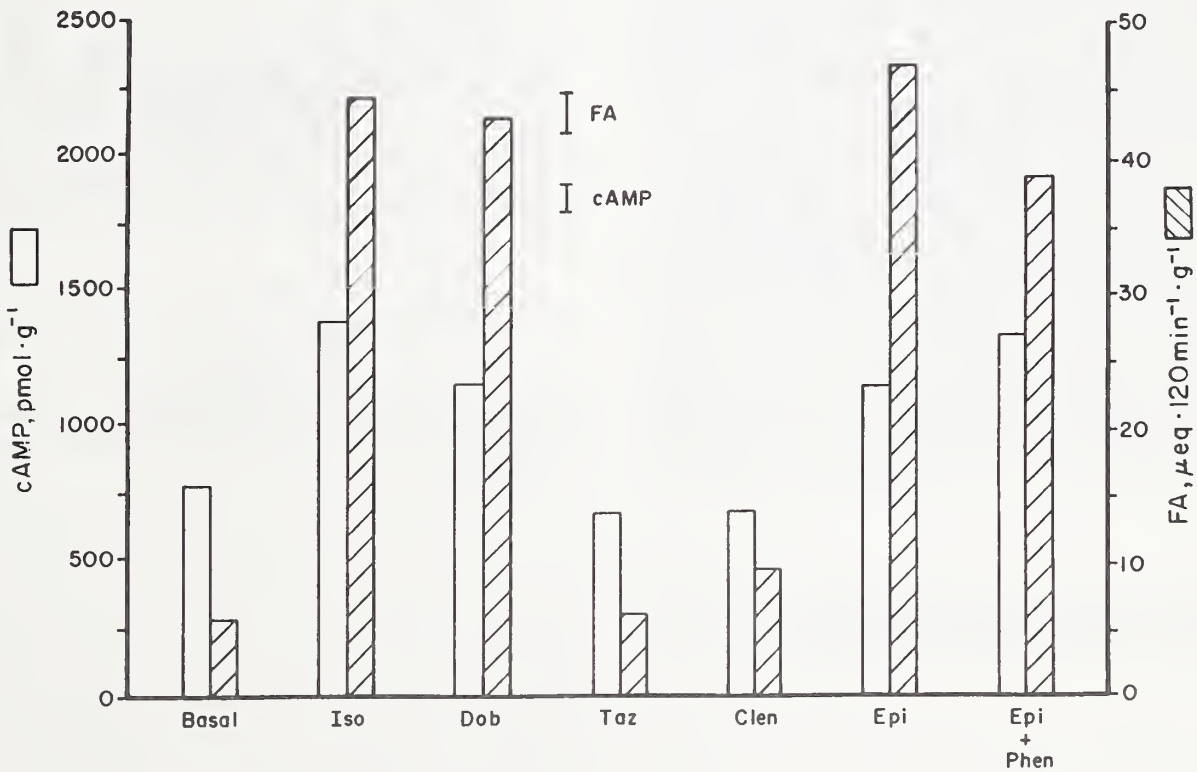

Figure 2—Response to various adrenergic agonists and antagonists. Additions to flasks were 10^{-5} M isoproterenol (Iso, beta-agonist); 3×10^{-5} M dobutamine (Dob, $beta_1$-agonist); 3.9×10^{-4} M tazolol (Taz, $beta_1$-agonist); 3.2×10^{-4} M clenbuterol (Clen, $beta_2$-agonist); 10^{-5} M epinephrine (Epi, alpha + beta-agonist) or 10^{-5} M phentolamine (Phen, alpha-antagonist). Release of FA and cAMP concentration was stimulated ($P < .05$) by Dob and Epi but not ($P > .05$) by Taz and Clen. Phentolamine did not enhance the agonistic Epi effect. Vertical bars indicate pooled SE for FA and cAMP.

Developmental Changes in Secretion of Growth Regulating Hormones in Pigs: The First Month of Life

John M. Klindt[1,2]

Growth hormone (GH; also called somatotropin) and prolactin (PRL) are products of the pituitary, whose level of secretion is developmentally regulated. These hormones are vital in endocrine regulation of the rate and pattern of animal growth. In growing swine, pituitary and circulating concentrations decline with age. We have reported the concentrations of growth hormone and prolactin in fetal pigs and the secretory patterns of these hormones in postweaning pigs. It was found that, near parturition, the concentrations of growth hormone in fetal pigs was over 100 ng/ml plasma. At 5 wk of age, the avg concentration of growth hormone in male pigs was near 6 ng/ml. The plasma concentration of prolactin was near 3 ng/ml prior to parturition and had risen to near 7 ng/ml by 5 wk of age in males. Other work at MARC has shown that circulating concentrations of the testicular steroid hormones—testosterone, estrone, and estradiol—change significantly during the first 28 days after birth in male pigs. These observations indicate that major endocrinological changes occur during the first month of postnatal life in male pigs.

Growth hormone and prolactin are secreted from the pituitary in an episodic manner; in other words, there is a burst of secretion followed by a period of low or basal secretion. This episodic pattern of secretion does not appear to fit a predictable rhythmic pattern. Evidence from laboratory animals, cattle, and sheep indicate that the pattern of secretion does have physiological importance. The secretory patterns can be defined in terms of overall mean, the average of the concentration of the hormone in all the samples collected during the sampling period; the baseline mean, the basal or threshold concentration; and the number and amplitude (height) of the secretory peaks. In our work we have found that it requires approximately 25 or more samples collected at time intervals approaching the half-life of the hormone in order to adequately define the secretory patterns.

Figure 1 presents the concentrations of growth hormone and prolactin in samples collected daily from male pigs. The concentrations of both hormones decline during the first 4 wk postnatally. The growth hormone concentrations during this period present a precipitous decline during the first wk and relatively steady values afterwards. Prolactin concentrations begin to decline at birth and this decline continues through the first 4 wk.

Figure 2 presents the patterns of growth hormone secretion in individual male pigs at 3, 9, and 18 days of age. Samples were collected via indwelling jugular cannulae at 5 to 20 min intervals for 4 to 5 hr. The overall mean concentration declined significantly with age, and baseline and number and amplitude of secretory peaks tended to decline with age. Again, these figures present the dynamic nature of GH secretion and the inexplicable failure of some individual animals to demonstrate that dynamic secretion (i.e., secretory peaks) during the sampling period.

The secretory patterns of prolactin in individual young boars at 3, 9, and 18 days of age are presented in Figure 3. Overall mean concentration and baseline concentration of prolactin declines during the first month in young boars. During this

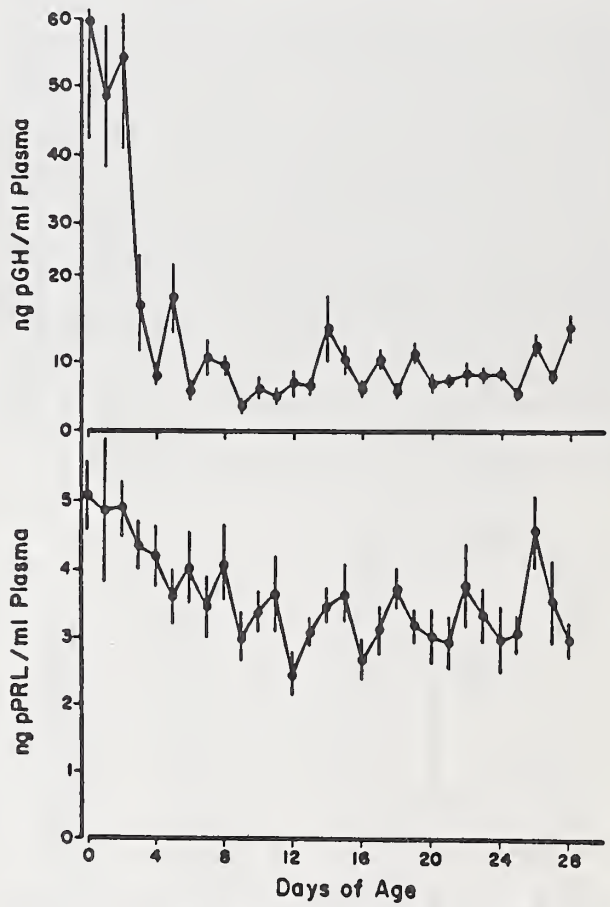

Figure 1—Daily plasma concentrations of growth hormone and prolactin in male pigs. Vertical bars represent standard error of the mean.

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[2]Full report published in Growth 50:516-525, 1986.

time, the apparent dynamic nature of prolactin secretion develops. Analysis of the patterns suggests that there are no prolactin secretory peaks at 3 days of age, and the presence of secretory peaks comes with maturity. Subjective examination of the patterns does not exclude the possibility that this conclusion is a consequence of the algorithm used to analyze the patterns. It is certainly evident, however, that during the first month of life secretion of prolactin is less dynamic than secretion of growth hormone.

The results presented herein and those published previously indicate that the circulating concentrations of porcine GH change with development. The maximal mean concentrations are measured at 90 to 100 days of gestation. Postnatally, the mean concentrations decline precipitously the first 2 days, and the decline continues, though less precipitously, through 24 wk of age. It appears that a major portion of the decline in mean GH concentrations is due to a decrease in amplitude of GH secretory peaks, as was reported for older pigs. The mean circulating concentrations of PRL also decline with postnatal development. During the first 18 days postnatally, this decline appears to be due to a decline in basal concentrations. After 5 wk of age, the decline appears to also be due to depressed episodic secretion.

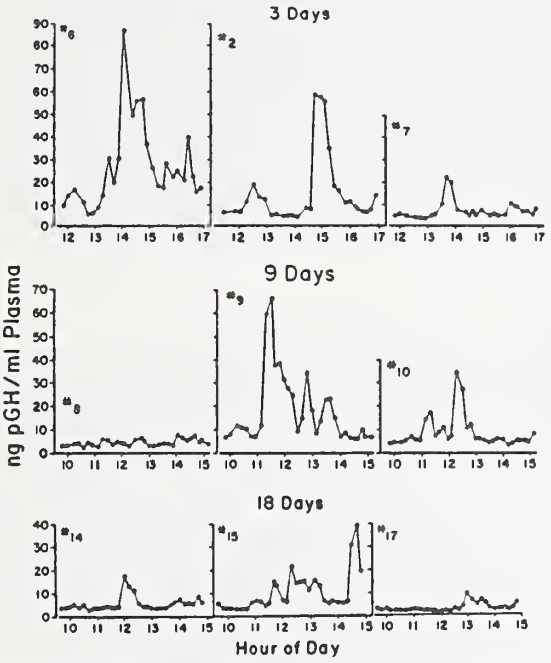

Figure 2—Temporal plasma concentrations of growth hormone in individual male pigs at 3, 9, and 18 days of age. The number in the upper left of each panel is animal identification.

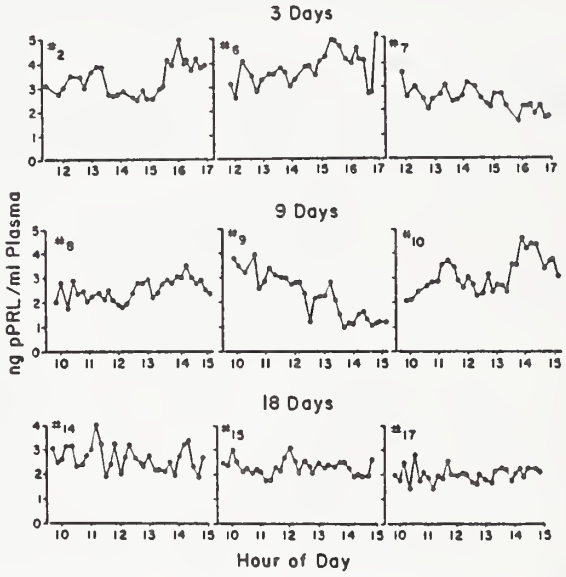

Figure 3—Temporal plasma concentrations of prolactin in individual male pigs at 3, 9, and 18 days of age. The number in the upper left of each panel is animal identification.

Compensatory Growth in Finishing Pigs After Feed Restriction

Harry J. Mersmann, Michael D. MacNeil, Steven C. Seideman, and Wilson G. Pond[1, 2]

Introduction

Compensatory growth after feed restriction has been demonstrated in pigs for many years. Classical studies indicate that pigs restricted in nutrient intake from birth to 16 wk, so that body wt was about one-half that of the pigs fed *ad libitum*, had an accelerated rate of body wt gain when refed *ad libitum* at 16 wk. It was demonstrated also that these refed pigs had less muscle and more fat in the carcass at 200 lb than pigs continuously fed *ad libitum*. Thus, the concept that compensatory growth following severe feed restriction yielded fatter animals was established. Many subsequent studies on pigs of various ages examined compensatory growth following feed restriction; much emphasis has been on feed restriction in the young pig and has been oriented toward poor postnatal nutrition and the retardation in growth at weaning, whereas other studies emphasized modest feed restriction (10 to 30%) and recovery from it in growing-finishing pigs.

These present studies were to establish whether modern fast-growing, lean crossbred pigs would rebound from severe feed restriction during the finishing phase of growth by compensatory growth and whether such growth would produce more carcass fat than lean. In contrast to younger pigs accreting mostly muscle mass, the older pig (about 110 lb) is at a stage of growth wherein carcass muscle accretion is rapid but fat accretion is also rapid, and the rate is accelerating. Ultrasound provided a technique to study the same pigs for alterations in fat thickness during these nutritional manipulations but did not allow sufficient assessment of muscle growth. Therefore, a second study using comparative slaughter techniques was conducted. Internal organs were weighed also in the latter study.

Procedure

Experiment 1. Sixteen crossbred (¼ Yorkshire, ¼ Chester White, ¼ Landrace, ¼ Large White) castrated male pigs were individually penned in an enclosed, temperature-controlled building. The pigs' average wt was 106 lb. Eight pigs were allowed *ad libitum* consumption (F group) of a corn-soybean meal diet containing 14% protein for 61 days. Another 8 pigs (RF group) were fed the same diet at .11 to .55 lb/day to achieve approximately a 20% loss of body wt in about 3 wk. After 19 days, the food given to the restricted group was gradually increased over a 1-wk period to *ad libitum* levels, and then was fed *ad libitum* until day 89 of the experiment.

Backfat depth and longissimus muscle area measurements were obtained ultrasonically on the right side of each live pig.

Experiment 2. This experiment used the same type of crossbred pigs and was similar to Exp. 1, except the pigs weighed 145 lb at day 0, the F group was fed for 63 days, and the RF group was restricted for 21 days and gradually refed to *ad libitum* levels over 1 wk, followed by *ad libitum* feeding until day 91 of the experiment. Experiment 2 used a comparative slaughter design; 8 pigs were slaughtered at day 0 and 8 pigs were slaughtered for each dietary group at days 21, 42, and 63 of the experiment. At day 91, 8 pigs from the RF group were slaughtered. Organ weights, carcass measurements and cutout, and fat and moisture determinations on the lean from the shoulder and ham were obtained after slaughter.

The loss period for the RF group is the period between days 0 and 19 or 21 for Exp. 1 or 2, respectively. Rates of increase for variables during the feeding stage for the F group (days 0 to 61 or 63 for Exp. 1 or 2, respectively) and for the RF group (days 19 or 21 to days 89 or 91 for Exp. 1 or 2, respectively) were derived by regression methods. Predicted values and their standard errors for each variable were calculated from the regression equations at constant wt (220 lb), constant time of feed (60 days on feed) and constant feed intake (420 lb). To conserve space, only a selected few of the predicted values are presented.

Results

During the loss period in Exp. 1, the RF pigs lost about 24% body wt; this appeared to be mostly fat loss, although only one muscle measurement (loin eye area; LEA) was made (Table 1).

Liveweight increased linearly from 106 lb in the pigs fed *ad libitum* (F) in Exp. 1; the rate of wt increase, from 81 lb, in the refed pigs (RF) was slightly greater (1.9 *vs* 2.21 lb/day). Feed intake increase was linear and intake was greater in RF than F pigs (8.5 *vs* 7.2 lb/day). The rate of increase in animal length was not significantly different between RF and F pigs (Table 1). All ultrasonic fat depths (except 1/5-1) and the fat area (LEFA) increased at a greater rate in the RF than F pigs. The only muscle measurement in this experiment, LEA, had a similar rate of accretion in RF and F pigs.

Table 1—Loss and gain of body components (Experiment 1)

Variable[a]	Group[b]	Gain period Rate	Loss period Day 0	Loss period Day 19
Length (in)	F	.184		
	RF	.198	35.8	34.8
Fat				
1/5-1 (in)	F	.012		
	RF	.013	1.01	.74*
1/2-1 (in)	F	.006		
	RF	.009*	.53	.35*
3/4-1 (in)	F	.008		
	RF	.014*	.69	.47*
1/2-3 (in)	F	.009		
	RF	.012*	.51	.30*
LEFA (in^2)	F	.060		
	RF	.078*	.98	.61*
LEA (in^2)	F	.055		
	RF	.061	2.03	1.81**

[a]Length was from base of skull to base of tail. Fat was measured ultrasonically at one-fifth, one-half, and three-fourths body length over the vertebral column (1/5-1, 1/2-1, and 3/4-1) and three-fourths the lateral distance over the longissimus muscle at one-half body length (1/2-3). Area of the longissimus muscle was measured ultrasonically at one-half body length (LEA), and fat area over the longissimus muscle (LEFA) was bounded by the skin, top of the muscle, 1/2-1 and 1/2-3.

[b]F = pigs fed *ad libitum*; RF = pigs restricted then refed *ad libitum*. There were eight pigs in each group and the pigs were each measured throughout the study.

*$P<.05$. **$P<.1$.

[1]Mersmann is a research chemist, Meats Unit, MARC; MacNeil is a research animal geneticist, Ft. Keogh Livestock and Range Res. Sta., Miles City, MT (formerly a research animal scientist, MARC); Pond is the research leader, Nutrition Unit, MARC; Seideman is employed by Bryan Meats, West Point, Mississippi (formerly a research food technologist, MARC).

[2]Details of this work are published in the J. Anim. Sci. 64:752-764, 1987.

Experiment 2 was of similar design to Exp. 1 but the pigs were 40 lb heavier at day 0. Although the loss of body wt was 20% over 21 days, the loss in carcass wt was only 8% (Table 2). Carcass fat depth measurements and LEA did not change ($P > .1$) during the wt loss period, but the direction of all fat depths suggested a minor loss of carcass fat (Table 2). The suggestion for minor loss of fat was evident also in the wt of dissected fat from the ham; ham lean (contains intramuscular and intermuscular fat) was decreased during wt loss (Table 3). The wt of the gut and organs associated with it dramatically decreased during the wt loss period; whereas, the heart and spleen wt did not decrease, but the kidneys weighed considerably less (data not indicated). Intraperitoneal fat associated with the mesenteries suspending the gut was not evaluated but could be important during feed restriction.

During the feeding periods, body wt increase in Exp. 2 and rates of gain were linear, and the RF group gained faster than the F group (2.2 *vs* 1.9 lb/day), as observed in Exp. 1. In contrast to Exp. 1, RF pigs in Exp. 2 did not have a greater rate of feed intake than F pigs (8.1 *vs* 7.6 lb/day). Also, in marked contrast to Exp. 1, rates of accretion of carcass fat were not different between F and RF pigs in Exp. 2 (Table 2). This result was evident in shoulder (data not shown) and ham composition, as well (Table 3).

At constant wt (extrapolated data not shown), the data consistently indicate that the RF pigs in Exp. 2 were not fatter than the F pigs, in contrast to the observation in Exp. 1. Rather, the RF pigs were leaner and more muscular and had larger skeletal mass than F pigs. Therefore, the accretion of fat was probably less efficient in RF than F pigs in Exp. 2, i.e., less fat deposition with the same feed intake. This is the exact opposite result of that observed in Exp. 1.

Refed pigs in both experiments gained body wt faster than pigs fed *ad libitum*, thus exhibiting compensatory growth. Although the growth rates were greater in RF than F pigs, these differences were small relative to others reported previously. Refed pigs in Exp. 1, but not Exp. 2, were fatter (as judged by measurements of subcutaneous fat) than pigs fed *ad libitum*. The two experiments were intended to duplicate each other, but there were inadvertent differences between them.

The starting wt (age) in the experiments was 40 lb different (because of pig and facility availability), possibly changing the physiological reaction to the wt loss and rehabilitation. The 24% wt loss in 106 lb pigs in Exp. 1 may have been more severe than the 20% wt loss in the 145 lb pigs in Exp. 2. At experiment initiation, the heavier pigs in Exp. 2 had more body fat, as evidenced by greater backfat depths than the lighter pigs in Exp. 1. The lighter Exp. 1 pigs lost considerable fat during the restriction period, but the heavier Exp. 2 pigs lost no, or only marginal (mostly nonsignificant), amounts of fat. Severity of muscle mass loss or internal organ wt loss cannot be compared for the two experiments because only LEA was measured and no organ wt were obtained in Exp. 1.

The experiments were in two different buildings, possibly changing the specific micro-environment, e.g., temperature, humidity, drafts, etc. Furthermore, Exp. 2 began in mid-September and ended in mid-December, whereas Exp. 1 began in mid-November and ended in mid-February. Thus, the temperature (not recorded) may have fluctuated more, the building may have been generally colder, or they may have had more drafts in Exp. 1 than 2.

Animals were the same breed and were born at slightly different times of the year, but the experiments were 3 yr apart, thus allowing the remote possibility for random divergence of physiological or growth characteristics, even though no selection was practiced. Furthermore, the two experiments could have differed solely by chance.

Regardless of the differences between experiments, the refed pigs in Exp. 1 ate more than the pigs fed *ad libitum*, as indicated by the rates of feed intake (Fig. 2) and the extrapolated feed to reach 220 lb body wt. The refed pigs in Exp. 2 did not have a greater rate of feed consumption than the pigs fed *ad libitum* (Fig. 2), and extrapolated feed consumption to constant wt (data not shown) was less in RF than F pigs. Furthermore, although the lighter F pigs in Exp. 1 had a lower rate of feed intake compared with the heavier F pigs in Exp. 2, as expected, the lighter RF pigs in Exp. 1 had greater feed intake rates than the heavier RF pigs in Exp. 2. The excessive deposition of fat during compensatory growth in Exp. 1 was associated with increased feed consumption.

Table 2—Loss and gain of body components (Experiment 2)

Variable[a]	Group[b]	Gain period Rate	Loss period Day 0	Loss period Day 21
Carcass wt (lb)	F	1.4		
	RF	1.5	96	87.6
Fat				
BF1 (in)	F	.013		
	RF	.014	1.33	1.25
BF2 (in)	F	.010		
	RF	.009	.60	.53
BF3 (in)	F	.010		
	RF	.009	.67	.61
BF4 (in)	F	.012		
	RF	.012	.66	.59
LEFA (in^2)	F	.120		
	RF	.119	2.5	2.56
Perirenal (lb)	F	.051		
	RF	.052	1.32	1.02
LEA (in^2)	F	.090		
	RF	.080	3.57	3.74

[a]Measurements were made on chilled carcass. Length was from first rib to aitch bone. Backfats were over the vertebral column at first rib, last rib, and last lumbar vertebrae (BF1, BF2, and BF3, respectively); and at the 10th to 11th rib interface, three-fourths the lateral distance over the longissimus muscle (BF4). The longissimus muscle area (LEA) was at the 10th to 11th rib interface, as was the fat area (LEFA) bounded by the skin, top of the muscle, vertebral column, and P_2.

[b]F = pigs fed ad *libitum*; RF = pigs restricted then refed ad *libitum*.

Table 3—Loss and gain of ham components (Experiment 2)

Variable	Group[a]	Gain period Rate	Loss period Day 0	Loss period Day 21
Ham				
Rough wt (lb)	F	.154		
	RF	.165	5.26	4.90
Bone wt (lb)	F	.011		
	RF	.008	1.05	1.19*
Fat (lb)	F	.047		
	RF	.051	1.70	1.51
Lean (lb)	F	.043		
	RF	.047	3.59	3.26**

[a]F = pigs fed ad *libitum*; RF = pigs restricted then refed ad *libitum*.

*$P < .05$.

**$P < .1$.

Divergent body composition in refed animals in the two similar experiments was unexpected because the pigs at either 106 or 145 lb should be at a point in their growth wherein both muscle and fat deposition are at a linear rate and both would be rapidly accreted. Certainly, it has been demonstrated many times in various species, including the pig, that excess caloric intake beyond that needed for maintenance and maximal protein accretion leads to excess fat accretion. The RF pigs in Exp. 1 ate more than the F pigs, but the reason they ate more is not clear; nor is it obvious why the two experiments were divergent in this respect.

The stage of growth at which a nutritional insult or rehabilitation occurs may have profound influence on the subsequent growth rates and composition of growth. It is well known and demonstrated routinely that modest restriction of feed intake to about 90% of *ad libitum* intake in growing-finishing pigs causes a reduction in fat deposition with no change in gain of lean mass. Compensatory growth rate during the rehabilitation phase from such a nutritional restriction has been demonstrated in pigs, but the extent of rehabilitation and the achieved body composition are probably dependent on age and extent of restriction, as well as many other unknown factors. Reports vary as to the effect of restriction in early stages of postnatal growth on subsequent growth. Perusal of the swine literature indicates the possibility that many divergent effects may occur and that breed, sex, age, or stage of development at time of restriction, degree of restriction (length and amount), age at time of rehabilitation, season, and environment may, singly or in combination, ultimately affect the growth rates and/or body composition in rehabilitation-type experiments.

In summary, these studies indicate that contemporary fast-growing crossbred pigs responded with compensatory growth during the refeeding period following severe feed restriction. However, the degree of increase in the growth rate was small in light of the severe feed restriction and concomitant wt loss. The body composition after compensatory growth may be dictated by a number of subtle variables in the individual experiment. A predominant factor in our experiments was whether the animals ate more during the refeeding period compared with animals continuously fed *ad libitum*, and, consequently, whether they were fatter than the controls. A second less tangible factor may be the extent of change in physiological status imposed by the wt loss during restriction. The restriction produced more loss of fat in Exp. 1 than 2, but it was not clear whether this reflected greater stress or how it may have influenced appetite during refeeding. Ultimately, the difference between the two experiments reported herein may not be great and may result from small differences in either the rate of muscle mass accretion, the rate of fat mass accretion, or the ratio between the two. Consequently, the observed response in a given experiment could represent a matter of degree of change in this ratio rather than the direction. Because such subtle differences in a given experiment may profoundly influence the outcome, biological principles about compensatory growth should be derived cautiously.

Growth and Adipose Tissue Metabolism in Young Pigs Fed Cimaterol with Adequate or Low Dietary Protein

Harry J. Mersmann, C. Y. Hu, Wilson G. Pond, Dan C. Rule, Jan E. Novakofski, and Stephen B. Smith[1, 2]

Introduction

Several analogs of the hormone adrenaline, when fed to growing animals, yield increased carcass muscle mass and decreased carcass adipose tissue mass. The effects on gain and feed consumption are less consistent, but, with some analogs, there is an increase in gain or a decrease in feed consumption or both, yielding improvement in efficiency of wt gain. Even in studies where there is no change in gain:feed ratio, if efficiency is calculated on the basis of the product of meat animal production, i.e., lean body mass, there is marked improvement in efficiency of production.

Because these compounds have been fed to pigs only at starting wt above 110 lb, we fed one of them, cimaterol, to pigs beginning at about 22 lb body wt to determine if the changes observed in carcass composition in older pigs depositing large amounts of lean and fat mass would be observed also in the young pig depositing more lean and less fat mass. Furthermore, because these adrenaline analogs increase lean mass in growing-finishing pigs, we tested whether feeding such a compound would alleviate some of the requirement for high levels of dietary protein in young, rapidly growing pigs that deposit a large proportion of body wt as lean mass.

Procedure

Crossbred castrated male pigs (1/4 Chester White, ¼ Landrace, ¼ Large White, ¼ Yorkshire) were weighed, stratified by wt, within strata randomly assigned to one of six experimental groups, and placed in individual pens. There were nine pigs per group, each from a different litter. Pigs had access to feed and water *ad libitum*.

The experiment had a 2 x 3 factorial arrangement of dietary protein (18 and 14%) and cimaterol treatments (0, .00055, and .0010 lb/lb feed).

Pigs were weighed at day 1 (fasted because of blood sampling) and every 2 wk (fed) until termination of the trial at 10 wk. Feed consumption was determined on a 2-wk basis. At 10 wk, pigs were slaughtered (fed), dehaired, and the feet and tail were removed. Fresh liver minus gall bladder contents, kidneys, spleen, heart minus blood, empty stomach, and perirenal fat wt were obtained. Carcasses were chilled at 41°F for 2 or 3 days, and then the right half was used to measure cold carcass wt, carcass length (first rib to aitch bone), and backfat (BF) at first and last rib and last lumbar vertebra (average of these three reported). At the 10th to 11th rib interface, longissimus muscle cross-sectional area (LEA), fat depth at three-quarters the lateral distance over the longissimus muscle (BF10), and fat cross-sectional area (LEFA) bounded by the skin, vertebral column, top of longissimus muscle, and BF10 were measured.

The right half of each carcass was frozen and ground. The ground carcass was sampled randomly for chemical analysis. Dry matter was the residue after the sample was lyophilized. Fat (ether extract) was determined on the dried sample by standard methods. Ash and nitrogen were determined on the ether-extracted sample. Protein is N x 6.25.

Data were analyzed with analysis of variance procedures (SAS, 1982) for a 2 x 3 factorial arrangement or one-way classification, as appropriate. Tests of differences among means were accomplished using the protected least significant difference method with the null hypothesis of equality of means rejected at the 5 or 10% level, as indicated.

Results

Pigs grew linearly (data not indicated) from day 1 to the end of the trial. Pigs fed the diet containing 18% protein gained wt faster and had heavier slaughter wt than pigs fed the diet containing 14% protein (Table 1). Feed intake was greater in the pigs fed 18% than in those fed 14% protein diets, and gain:feed ratios were the same in all groups (Table 1). Cimaterol had no effect on gain, feed consumption, or gain:feed ratio at either cimaterol dose or dietary protein level (Table 1).

The level of dietary protein significantly influenced most carcass variables, but there were no significant cimaterol effects (Table 2). Carcass length and longissimus muscle area were greater in pigs fed high than in those fed low dietary protein. Backfat thickness, LEFA, and perirenal fat wt were less in pigs fed 18% compared with pigs fed 14% dietary protein.

Chemical analysis of the ground carcass, when each chemical component was extrapolated to carcass wt and adjusted for slaughter wt, indicated more dry matter wt and fat mass, less crude protein mass, equal ash mass in pigs fed 14% compared with those fed 18% dietary protein (Table 3). There were no significant effects of cimaterol on carcass chemical composition (Table 3).

The 18% protein diet was selected to provide adequate protein (NRC, 1979) over the entire experiment, whereas the 14% protein diet was selected to provide a suboptimal protein intake, which might allow the manifestation of a protein sparing effect of cimaterol. This study used fast-growing (1.7 lb/day), castrated male pigs that had gain:feed ratios of about .39 when fed an 18% protein diet. Lower dietary protein content (14%) decreased rate of gain (1.5 lb/day), but also lowered feed intake, so the gain:feed ratio remained the same. Pigs fed 14%

Table 1—Growth and feed consumption

Variable	Diet protein[a]	Drug[b] C	LD	HD	Sig.[c]
Slaughter wt, lb	H	140.1	137.7	145.4	P
	L	128.0	129.4	125.8	
Daily gain, lb	H	1.67	1.64	1.74	P
	L	1.51	1.52	1.47	
Gain:feed	H	.382	.401	.400	
	L	.389	.395	.393	

[a]H = 18% crude protein in diet, L = 14% crude protein in diet.

[b]Cimaterol in diet at 0 (C), .00055 (LD), or .0010 (HD) lb/lb diet. Pigs weighed 19.2 lb at the start.

[c]Data analyzed by analysis of variance. P = dietary protein effect (P<.05).

[1]Mersmann is a research chemist, Meats Unit, and Pond is the research leader, Nutrition Unit, MARC; Hu is an assistant professor, Oregon State University, Corvallis; Novakofski is an associate professor, University of Illinois, Urbana; Rule is an assistant professor, University of Wyoming, Laramie; and Smith is a professor, Texas A&M University, College Station (Hu and Rule were formerly research associates and Smith was formerly a research chemist, Meats Unit, MARC).

[2]Details of this work are published in the J. Anim. Sci. 64:1384-1394, 1987.

compared with 18% dietary protein had shorter carcasses and less muscle mass on a slaughter wt-adjusted basis, as evidenced by smaller longissimus muscle area, a lower percentage of carcass protein and H_2O, and less carcass protein mass. These pigs also had more fat mass on a slaughter wt-adjusted basis, as evidenced by average backfat depth, backfat area, perirenal fat wt, percentage of carcass fat, and lb carcass fat. Thus, the suboptimal protein status of pigs fed low dietary protein was demonstrated in this experiment, but the result showed no evidence of a protein sparing effect of cimaterol in rapidly growing pigs over the body wt range of 22 to 132 lb.

This study demonstrated no effect of feeding the beta-adrenergic agonist cimaterol to fast-growing pigs from about 22 lb body wt. It should be noted that this trial ended, after 10 wk of feeding, at about the body wts where other published trials and cimaterol- or clenbuterol-fed pigs began. The lack of drug effects on carcass composition may have resulted from several possibilities. Firstly, the concentrations of cimaterol chosen were within the effective dose range for finishing pigs but may have been too high or too low for the young pigs. A typical dose x response curve has a no-effect portion, an increasing effective portion, a plateau, a decreasing effective portion, and finally a no-effect of less-than-control response.

The cimaterol concentrations fed in the present study may not have been correct because they could have fallen on any of several portions of the dose x response curve for the young pigs. Secondly, it is possible that cimaterol is absorbed, distributed *in vivo*, or excreted differently in young compared with older pigs, so that the pharmacodynamics are entirely different at divergent ages. Thirdly, some or all of the tissues that respond to the drug *in vivo* may not do so in young animals because of low receptor number during these stages of development, low affinity of the receptor for cimaterol at this stage of development, poor receptor coupling to intracellular processes such as cAMP production or the intracellular system(s) that execute the yet unknown mechanism(s) of cimaterol, or more extensive desensitization, i.e., down regulation in tissue(s) affected by cimaterol at this stage of development than later in the growing-finishing phase when cimaterol changes porcine growth. Fourthly, age-related differences in metabolic regulation in responsive tissue may not allow the effect to occur at these young ages, or such differences may even counteract the effect of beta-adrenergic agonist. Fifthly, the changes in carcass composition in pigs fed beta-adrenergic agonists are generally of lesser magnitude than those observed in cattle or sheep. Consequently, the ability to detect such changes in a small animal may be diminished. Finally, because the dietary energy or the protein content can markedly influence body composition in growing pigs, it is possible the 18% protein and(or) the energy content of the diet were not sufficient to support additional muscle accretion in the presence of cimaterol in the rapidly growing pigs in this study (1.7 lb gain/day). The 18% protein in the diet met the NRC requirement at 22 to 44 lb and far exceeded it above 44 lb body wt, whereas the energy content was at the NRC requirement (about 7,040 kcal metabolizable energy/lb/day).

The present study does not negate a beta-adrenergic agonist effect on carcass muscle and fat mass in young growing pigs, but does indicate the need for an extensive and encompassing dose x response study and, possibly, an investigation of the interaction of dietary energy level with the response so such a judgment can be made.

Table 2—Carcass variables

Variable	Diet protein[a]	Drug[b] C	LD	HD	Sig.[c]
Backfat, cm[d]	H	2.60	2.73	2.62	P
	L	3.03	2.86	3.01	
BF10, cm[d]	H	2.02	2.13	2.02	P
	L	2.51	2.43	2.49	
Fat area (LEFA), cm^2 [d]	H	15.9	18.8	16.5	P(P<.1)
	L	20.2	18.7	18.5	
Perirenal fat, g[d]	H	477	478	486	P(P<.1)
	L	564	561	514	
LEA, cm^2 [d]	H	22.0	22.6	23.0	P
	L	21.6	19.7	19.6	

[a]H = 18% crude protein in diet, L = 14% crude protein in diet.

[b]Cimaterol in diet at 0 (C), .00055 (LD), or .0010 (HD) lb/lb diet.

[c]Data analyzed by analysis of variance. P<.05 unless indicated otherwise. P = dietary protein effect.

[d]Data adjusted with slaughter wt as a covariate (P<.05).

Table 3—Carcass chemical composition

Variable	Diet protein[a]	Drug[b] C	LD	HD	Sig.[c]
Dry wt, lb[d]	H	20.5	21.2	20.7	P
	L	22.1	22.6	21.6	
Fat wt, lb[d]	H	11.8	12.1	11.9	P
	L	13.6	13.9	13.2	
Protein wt, lb[d]	H	7.4	7.7	7.5	P, D (P<.1)
	L	7.1	7.4	7.1	
Ash wt, lb[d]	H	1.42	1.43	1.41	
	L	1.38	1.45	1.35	

[a]H = 18% crude protein in diet, L = 14% crude protein in diet.

[b]Cimaterol in diet at 0 (C), .00055 (LD), or .0010 (HD) lb/lb diet.

[c]Data analyzed by analysis of variance. P<.05 unless indicated otherwise. P = dietary protein effect; D = cimaterol effect.

[d]Data adjusted with slaughter wt as a covariate (P<.05).

Boar Sexual Behavior and Evaluation Technique

Donald G. Levis, J. Joe Ford, and Ronald K. Christenson[1]

Introduction

Pork producers continuously express concern about young, replacement boars not having sexual interest, older boars losing sexual interest, boars taking a considerable amount of time to get sexually stimulated, boars not being able to copulate, and boars physically abusing females. Research on sexual behavior of the boar has received little attention compared to other phases of the boar's reproductive capacity, such as sperm production. Sexual behavior does have a dramatic effect on the overall reproductive efficiency of a boar. Sexual behavior in boars has been previously assessed by evaluating different traits, such as time to copulation, number of copulations within a designated time, and subjective scores. The purpose of the following experiment was to: 1) determine the relationship between an initial evaluation method and three subsequent methods, and 2) determine whether a boar's observed sexual behavior with a tethered female or group of females in the presence of humans is representative of his spontaneous sexual behavior when housed with a group of females.

Procedure

Initial-evaluation. Forty 10-mo-old boars were evaluated for sexual behavior in a 5-min standardized evaluation procedure. Each boar was placed in the test pen (Fig. 1) with an ovariectomized estrous-induced gilt tethered in a separate pen within the test pen for a period of 1 min before the evaluation. The familiarization period permitted the boar to investigate the pen and allow the estrous-induced female to obtain a strong, standing position. After the familiarization period, the boar was allowed access to the side and rear of the tethered gilt for 5 minutes.

The sexual behavior traits evaluated were time to first mount, time mounted with penis exposed, time mounted with penis unexposed, time ano-genital sniffing, time nosing side, and elapsed time to copulation. These behavioral characteristics were recorded separately to the nearest 1 sec for each evaluation. A sexual behavior index score was calculated for each boar by using the index in Table 1. The index gave the highest score to boars with the highest sexual activity. Boars were evaluated four times on two consecutive days for 2 wk.

After averaging the four initial evaluation scores for each of the 40 boars, 18 boars were selected and classified as having high, medium, or low levels of sexual behavior. Four wk after the initial evaluation, the 18 boars were randomly assigned within classification to one of three alternative methods for evaluating sexual behavior. All boars were evaluated by method A, B, and C.

Method A.—Tethered female, 10 min. This method was exactly the same as the one used to initially evaluate and classify the boars, except the boars had 10 min of direct contact with the female. The same index was used. Boars were evaluated on two consecutive days.

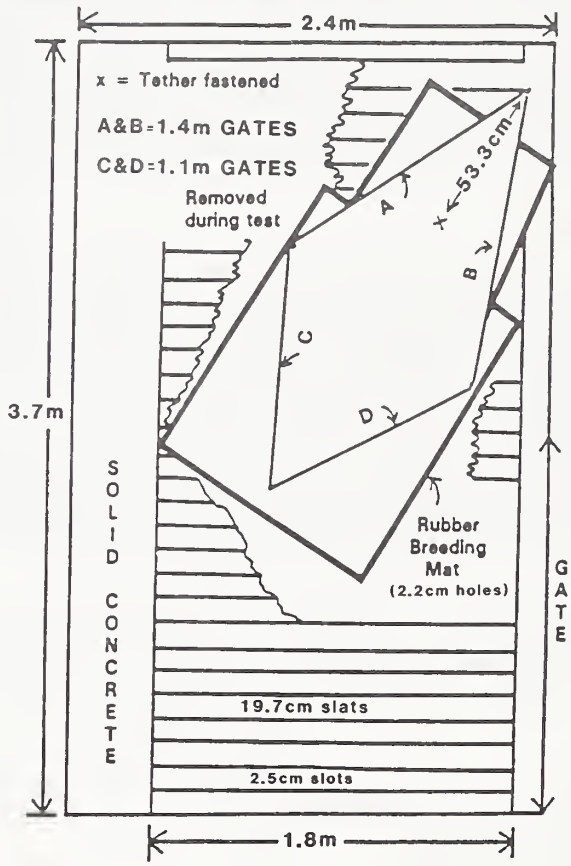

Figure 1—Evaluation test pen.

[1]Levis is a reproductive physiologist, Animal Science Department, University of Nebraska-Lincoln; Ford is a research physiologist, and Christenson is the research leader, Reproduction Unit, MARC.

Table 1—Sexual behavior index used during initial evaluation to classify boars

$$SBI = \left(\frac{DOE - ET\ FM}{DOE}\right) + \frac{TAGS}{DOE} + \frac{TMNP}{DOE} + \left(\frac{TNS}{DOE} \times 2\right) + \left(\frac{TMP}{DOE} \times 3\right) + \left(\frac{DOE - ETC}{DOE} \times 5\right)$$

where SBI = Sexual behavior index score
DOE = Duration of evaluation
ET FM = Elapsed time to first mount
TAGS = Time ano-genital sniffing
TMNP = Time mounted with penis not exposed
TNS = Time nosing side
TMP = Time mounted with penis exposed
ETC = Elapsed time to copulation

Method B.—Female group, 10 min. Two estrous and one non-estrous females were maintained as a group in an 8 x 12 ft pen. Boars had 10 min of direct physical contact with females. The same sexual behavior traits were recorded as in the evaluation with tethered females, plus the amount of time spent head mounted. Boars were evaluated on two consecutive days.

Method C.—Cohabitation. Three pens (8 x 12 ft) with three females per pen were established so one boar from each level of sexual behavior classification could be evaluated simultaneously. Two days before entering a pen of females, each boar was individually housed in a 4 x 12 ft pen adjacent to the females. A preliminary study indicated that boars previously housed for at least 30 days in a 2 x 7 ft stall needed an exercise period before being turned into a pen of females. Boars were only allowed visual and fence-line contact with their respective pen of females. After the exercise period, a 125-hr, unrecorded time block was allowed for establishment of social interactions among the boar and non-estrous females. Sexual behavior was videotaped for 113 continuous hr, beginning 48 hr after two females (ovariectomized gilts) received a single intra-muscular injection of 1.5 mg of estradiol benzoate. The 113-hr time block was used to evaluate a boar's sexual behavior when females were coming into estrus, were in estrus, and were going out of estrus. Time mounted was used as the evaluation criteria for the cohabitation ranking.

Results

Correlations. The correlation of initial evaluation method with three subsequent evaluation methods for various sexual behavior traits is presented in Table 2. Initial values for the sexual behavior index score, time to first mount, time penis first seen, time to intromission, and length of time mounted were significantly correlated with the corresponding values for tethered female (10-min) and female group (10-min) evaluations. Total time mounted was significantly correlated between initial and cohabitation methods. Total time mounted was used to calculate the correlation between the initial and cohabitation methods because individual sexual behavior traits could not be measured accurately during cohabitation.

Table 2—Linear correlation (r) between initial evaluation method and three subsequent evaluation methods for sexual behavior traits

Trait	Tethered Female (10 min)	Female Group (10 min)	Cohabitation (113 hr)
Sexual behavior index score	.62**	.64**	—
Time to first mount	.54*	.63**	—
Time penis first seen	.68**	.68**	—
Time to intromission	.64**	.58*	—
Length of time mounted	.78**	.82**	.53*

*P<.05; **P<.01

High-level classification. Three of six boars (50.0%) initially classified as having a high level of sexual behavior remained in the top six (top 33.3%) positions, and the other three boars moved to the middle classification when subsequently evaluated with a tethered female for 10 min (Fig. 2) and a group of females for 10 min (Fig. 3). During cohabitation, four of six boars (66.7%) remained in the top six positions while one boar moved to the middle and one to the low classification (Fig. 4). The boar that moved to the low classification did mate twice when evaluated with a tethered female, once when evaluated with a group of females, and five times when evaluated in a cohabitation environment.

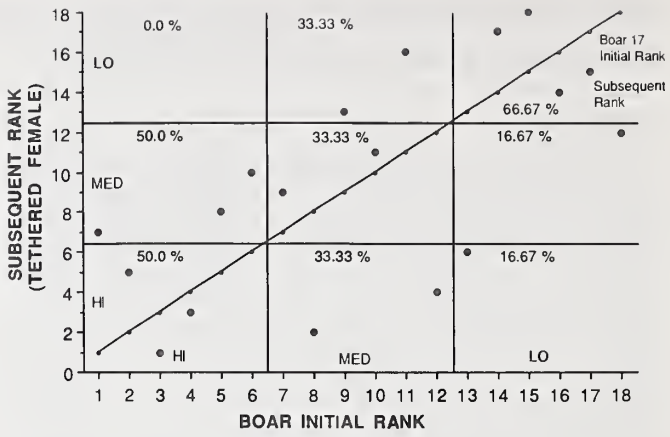

Figure 2—Subsequent rank and distribution within behavior classification of boars when evaluated with a tethered female (10 min) as related to initial rank. Rank is based on SBI score (r_S = .66; P<.01).

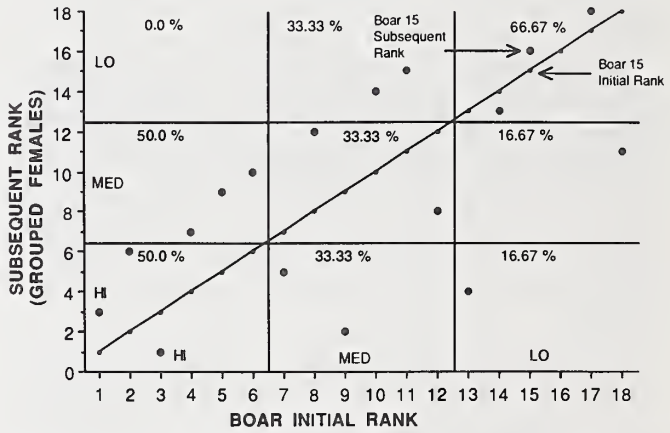

Figure 3—Subsequent rank and distribution within behavior classification of boars when evaluated with a group of females as related to initial rank. Rank is based on SBI score (r_S = .67; P<.01).

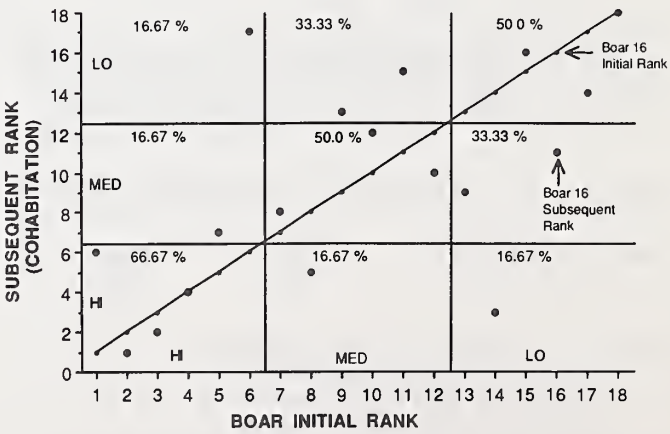

Figure 4—Subsequent rank and distribution within behavior classification of boars when evaluated in a cohabitation environment with females as related to initial rank. Rank is based on total time mounted (r_S = .71; P<.01).

Medium-level classification. Two of six boars (33.3%) initially assigned as having a medium level of sexual behavior remained in the middle classification; whereas, two boars moved to the high classification and two moved to the low classification when evaluated with a tethered female or group of females for 10 minutes. When the boars were evaluated in a cohabitation environment, 50% remained in the middle classification, 33.3% moved to the low classification, and 16.7% moved to the high classification. All medium-level boars did mate twice when evaluated with a tethered female or group of females for 10 min; however, only 50.0% mated during the cohabitation period.

Low-level classification. Four of six boars (66.7%) initially assigned as having a low level of sexual behavior remained in the bottom six positions while one boar moved to the middle classification and one boar moved to the high classification when subsequently evaluated with a tethered female or group of females for 10 min. The low-level boar that moved to the top 33.3% mated twice when evaluated with a tethered female or group of females for 10 minutes. This boar did not mate in the cohabitation environment. During cohabitation, three of six low-level boars remained in the bottom six positions; whereas, two boars moved to the medium classification and one boar moved to the high classification. All three boars showed considerable mounting activity during cohabitation but failed to mate.

This change in rank might be expected since the initial sexual behavior ranking equation had a weighted component for ability to copulate; whereas, the cohabitation rank is based solely on length of time mounted.

All levels of classification. Subsequent rank for all boars was significantly correlated with initial rank when evaluated with a tethered female ($r = .67$, Fig. 2), group of females ($r = .67$, Fig. 3), or cohabitation environment ($r = .71$, Fig. 4).

Cohabitation matings. The number of matings per boar and the number of different estrous females mated by each boar during the cohabitation period are shown in Table 3. The average number of copulations for the high-, medium-, and low-level classifications was respectively 4.67, 2.33, and .33. The initial sexual behavior index correctly identified 83.3% (5 of 6) of the high indexing boars that would have a high copulation rate during cohabitation. The initial index also correctly identified 100% (6 of 6) of the low indexing boars that would have a low copulation rate during cohabitation. While seven of the top nine boars mated at least four times, only three boars mated both estrous sows. The absence of a human evaluator did not appear to change the mating results.

In conclusion, ranking boars by the initial sexual behavior index was a reliable indicator of subsequent mating performance for high and low sexual behavior classifications; however, the initial index was less reliable for medium sexual behavior classification.

Table 3—Number of copulations and number of females bred during cohabitation

Initial rank	Number copulations	Number females bred
1 H[a]	9	2[b]
2 H	4	1
3 H	5	1
4 H	4	2
5 H	1	1
6 H	5	1
7 M	0	0
8 M	7	2
9 M	5	1
10 M	2	1
11 M	0	0
12 M	0	0
13 L	0	0
14 L	0	0
15 L	0	0
16 L	0	0
17 L	2	1
18 L	0	0

[a]H = High; M = Medium; L = Low

[b]Two estrous females were available for mating

Differentiation of Sexual Behavior in Swine

J. Joe Ford and Ronald K. Christenson[1, 2]

Introduction

For a number of years, we have investigated sexual development and puberty in swine. One component of this research is studies of how development of sexual behavior differs between boars and gilts. Such research is targeted to understanding and reducing the incidence of boars with inadequate sexual behavior and gilts that have silent estrus (behavioral anestrus). Sexual behavior in mature pigs is influenced by two actions of steroid hormones (estrogens, progesterone, and androgens). These actions are to 1) cause permanent modification (differentiation) of neural processes during early development of the pig and 2) activate and maintain sexual behavior in adult pigs. Previously, we observed female sexual behavior in estrogen-treated, mature barrows that were castrated before 2 mo of age and concluded that a major component of sexual differentiation in boars occurs after birth.

In two current studies, estrogen concentrations in male and female fetuses were examined, and the effect of testosterone treatment of young barrows on their sexual behavior as adults was evaluated further. Fetal estrogen concentrations were of interest because the primary theory on sexual differentiation in males is that conversion of androgen to estrogen within the brain causes differentiation of sexual behavior. This theory is based on data from rodents. We know that estrogen production by the placenta of sows is high during late pregnancy; thus, are male and female fetuses exposed to similar or different concentrations of estrogen? Treatment of young barrows with testosterone was to determine if this hormone could modify the sexual behavior of these males from female-typical behavior to male-typical behavior.

Procedure

In the first study, surgery was performed on pregnant females on different days of gestation, and amniotic fluid and umbilical arterial blood samples were obtained from male and female fetuses. These samples were assayed for concentrations of total unconjugated estrogens and estrone sulfate. In the second study, boars were castrated within 48 hr of birth or at 3, 6, or 8 mo of age. One-half of the barrows castrated shortly after birth were treated with testosterone propionate (intramuscularly) once per wk from 3 to 6 mo of age. At 9.5 mo of age, all barrows were treated with a single injection of estradiol benzoate and evaluated twice daily for female sexual behavior (rigid standing response to back pressure) with a mature boar. This procedure was repeated 3 wk later.

Results

The concentrations of unconjugated estrogens and estrone sulfate were similar in amniotic fluid and fetal serum of male and female fetuses; therefore, data within day were pooled for both sexes and presented as changes across time (Fig. 1 and 2). Estrogen concentrations in amniotic fluid were elevated at day 30, declined through days 40 to 50, and increased during the last one-half of gestation. In fetal serum, estrogen concentrations increased after day 60 of gestation. Because estrogen concentrations were similar in both male and female fetuses, we conclude that estrogens are not involved in sexual differentiation during this period of fetal development.

All barrows castrated at birth and treated with estradiol benzoate at 9.5 mo of age showed female sexual behavior (Fig. 3). Significantly fewer barrows castrated at 8 mo of age or barrows castrated at birth and treated with testosterone propionate from 3 to 6 mo of age showed female sexual behavior after estradiol benzoate treatment. We conclude that differentiation of one aspect of sexual behavior in boars (rigid standing response after estrogen treatment) is likely due to the increase in testosterone secretion during early pubertal development (3 to 6 mo of age). As noted in our previous studies, differentiation of sexual behavior in the pig takes place late in development as compared to other species that have been investigated.

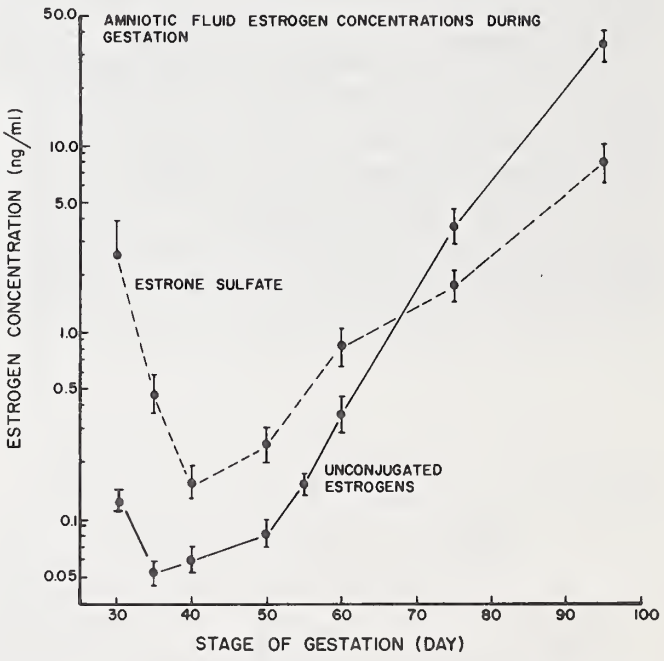

Figure 1—Mean concentrations of unconjugated estrogens and estrone sulfate in the amniotic fluid of prenatal pigs.

[1]Ford is a research physiologist, and Christenson is the research leader, Reproduction Unit, MARC.

[2]Full reports of this research were published in Swine in Biomedical Research 1:191, 1986, M.E. Tumbleson ed. and Biol. Reprod. 36:581, 1987.

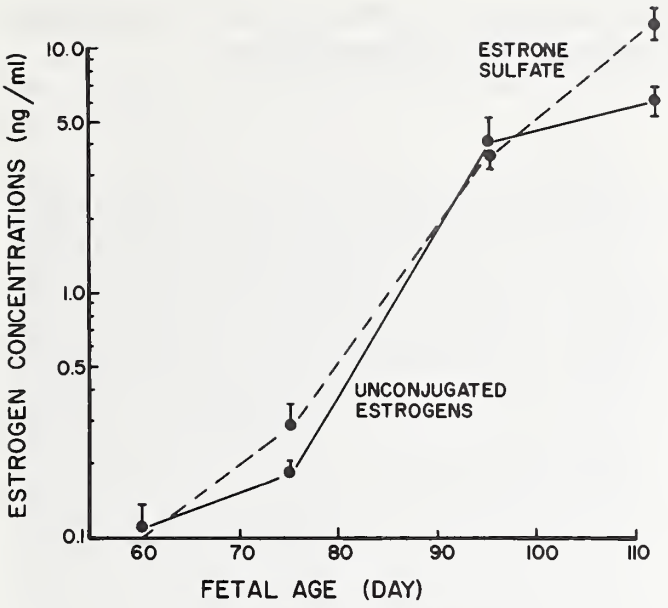

Figure 2—Mean concentrations of unconjugated estrogens and estrone sulfate in umbilical arterial serum of fetal pigs.

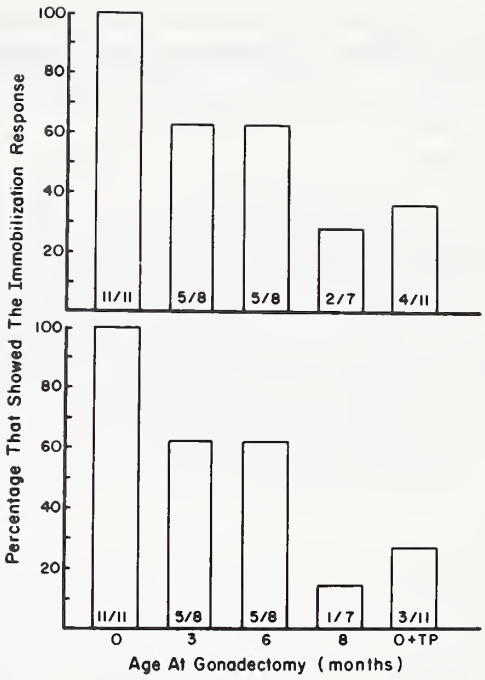

Figure 3—Proportion of estrogen-treated barrows in which the rigid standing response to back pressure was observed in the presence of a mature boar. The first evaluation was conducted at 9.5 mo of age (upper panel) and a second evaluation was conducted 3 wk after the first (lower panel).

Interval to First Postweaning Estrus and Causes for Leaving the Breeding Herd in Landrace, Large White, Yorkshire, and Chester White Females After Three Litters

Ralph R. Maurer, J. Joe Ford, and Ronald K. Christenson[1, 2]

Introduction

Failure to exhibit estrus after weaning a litter of pigs is very common, especially after females produce their first litter. This failure to exhibit estrus is costly to the producer. Several factors, such as housing, season, and nutrition during lactation have been shown to influence the number of females failing to exhibit estrus after weaning.

The objective of this investigation was to determine the interval from weaning to first estrus after the first, second, and third litters and lactation in Large White, Landrace, Yorkshire, and Chester White breeds located at MARC. Disposal records were accumulated to determine reasons for sows leaving the herd.

Procedure

The numbers of females farrowing or available to mate are listed by yr, number of litters produced, and breed in Table 1. Large White (LW) and Landrace (L) gilts were descendants of gilts purchased from the Pig Improvement Company, Spring Green, Wisconsin, while Yorkshire (Y) and Chester White (CW) females were descendants of animals purchased from several seed stock producers in the Midwest. All animals were maintained in confinement with 14 hr of light per day. Building temperatures were maintained at 60 to 65°F in winter and in summer; upon reaching 80°F, misters or evaporating cooling units were used. Over the three years, females at 11 to 12 mo of age farrowed their first litter in February and March, second litter in July and August, and third litter in December to January. All gilts were mated to boars of the same breed as the breed of gilts, whereas second and third litter females were mated to boars of the same breed or of a different breed. During gestation, females were fed 3.5 lb of a 13% crude protein diet during days 0 to 80 and 5.5 lb from day 81 to farrowing. During lactation, the females were fed *ad libitum* a 16% crude protein diet. At 28 to 30 days of age piglets were removed from the sows, who were then placed in pens of 12 to 20 females in 1978 and 1979 or individual stalls in 1980. Feed was withheld for 24 hr after weaning, and, thereafter, each female received 4 lb of 12% crude protein diet daily. Estrous behavior was detected by placing a boar in the pen of females for approximately 10 min or allowing a boar to roam in front of sows in individual stalls while sows were checked by back pressure for the immobilization stance. If a female demonstrated the immobilization stance, she was considered in estrus and was mated. The day of weaning was designated as day 0. All females were observed for estrus for 30 days. If a female was not detected in estrus within 30 days, she was removed from the experiment. Females that were mated and demonstrated estrous behavior after 42 days were also removed from the experiment. Other reasons for removing a female from the experiment were chronic lameness, death, uterine prolapse, and herdsmen error.

[1]Maurer and Ford are research physiologists, and Christenson is the research leader, Reproduction Unit, MARC.

[2]The full report of this work was published in J. Anim. Sci. 61:1327-1334. 1985.

Table 1—Number of females farrowed as gilts and exhibiting estrous behavior within 30 days after the first, second, and third litters

		Breed				
Yr	Litters Produced	Large White	Landrace	Yorkshire	Chester White	Total
1978	F[a]	26	24	23	15	88
	1	24	21	19	10	74
	2	24	19	19	9	71
	3	23	12	16	7	58 (65.9)[b]
1979	F[a]	27	27	26	20	100
	1	24	22	15	15	76
	2	18	19	14	11	62
	3	15	19	14	8	56 (56.0)
1980	F[a]	40	41	20	16	117
	1	36	32	9	8	85
	2	24	29	7	6	66
	3	21	26	6	3	56 (47.9)
Total	F[a]	93	92	69	51	305
	1	84	75	43	33	235
	2	66	67	40	26	199
	3	59	57	36	18	170
		(63.4)[b]	(62.0)	(52.2)	(35.3)	(55.7)

[a]Number of gilts that farrowed.

[b]Numbers in parentheses are percentages of females that exhibited estrous behavior by 30 days postweaning after weaning the third litter.

Results

The interval from weaning to estrus was different among breeds and after the first and second litters. The interval between weaning and estrus was not different between the second and third litters. Means for the LW, L, Y, and CW breeds over the three litters were 6.7, 5.6, 7.4, and 8.6 days, respectively, for the females exhibiting estrus within 30 days. Mean interval for first, second, and third litters was 9.4, 6.0, and 5.8 days, respectively. Breed of boar did not influence the interval between weaning and first estrus.

Table 2 gives the percentage of sows exhibiting estrous behavior by days 7, 14, and 30 after the first and combined second and third litters. Percentages for the second and third litters were similar and were combined. A higher percentage of LW and L sows showed estrus by seven days after weaning the first and subsequent litters than did Y and CW sows. Landrace sows (94.3%) had the highest rate of females exhibiting estrus, while CW sows (78.0%) had the lowest rate by seven days after weaning in the combined second and third litters. Breeds differed in the percentage of females showing estrus for the 30 days after weaning the first litter and combined second and third litters.

Number of piglets born alive and number of piglets weaned influenced the interval between weaning and estrus. As the number of piglets born alive increased and(or) number of piglets weaned increased, the interval between weaning and estrus increased.

Prefarrowing and weaning wt and wt loss during lactation of sows differed among breeds ($P < .01$). Prefarrowing wt averaged 391.6, 382.6, 365.2, and 362.6 lb for LW, L, Y, and CW sows, respectively. Weight loss differed ($P < .01$) after each litter with 22.4, 39.2, and 25.7 lb losses after the first, second, and third litters, averaged over breeds and years. Weight loss during lactation and interval from weaning to estrus had a significant ($P < .05$) linear relationship. For each 2.2 lb wt loss, interval from weaning to estrus increased by .05 days.

Percentage of sows farrowing did not differ among breeds, but fewer ($P < .01$) bred gilts farrowed (84.7%) than sows (91.8%). The percentage of sows that failed to return to estrus by 30 days after weaning was influenced by breed, yr, and the number of litters produced. More Y (37.7%), CW (23.5%), and L (18.7%) females failed to exhibit estrus than LW (6.5%) females. Percentage of females failing to exhibit estrus by yr were 13.6, 19.0, and 26.5 for 1978, 1979, and 1980, respectively. After first, second, and third litters, the percentage of females not detected in estrus was 16.1, 2.3, and 2.0, respectively.

Sows leaving the herd for death, lameness, or failure to maintain pregnancy are shown in Table 3. More CW females died (17.6%) as compared with other breeds (4.3%). Percentage of females removed by lameness was not influenced by breed or yr. Percentage of females which failed to maintain a pregnancy differed ($P < .01$) by breed and yr. More LW (19.4%) and CW (19.6%) sows returned to estrus after 42 days of mating than did L (5.4%) and Y (2.9%) sows. Percentages of females failing to maintain pregnancy by yr were 5.7, 10.0, and 17.1 for 1978, 1979, and 1980, respectively. The percentage of females failing to maintain pregnancy increased as the number of litters increased in the LW and L sows, while Y and CW sows had a constant percentage of pregnancy maintenance as number of litters produced increased. This resulted in an interaction by breed and number of litters produced.

Number and percentage of females available to produce a fourth litter are presented in Table 1. Breeds differed ($P < .01$) in the percentage of females available to produce a fourth litter with 63.4, 62.0, 52.2, and 35.3% available, respectively, for LW, L, Y, and CW breeds. The percentage of sows available to produce a fourth litter decreased by yr as 65.9, 56.0, and 47.9% were available for 1978, 1979, and 1980, respectively. A breed x yr interaction was also found. The percentage of LW, L, and CW sows available for a fourth litter decreased with yr, whereas the percentage of L sows available for a fourth litter increased with years.

This study indicated that reproductive problems (31.8%) (i.e., failure to return to estrus after weaning, 20.3%, and failure to maintain pregnancy, 11.5%) were the main reasons 44.3% of the females were culled from the breeding herd before the fourth litter.

Table 2—Percentage of females showing estrus as related to breed and days postweaning

Days postweaning	Breed							
	Large White		Landrace		Yorkshire		Chester White	
	1[a]	2 and 3[b]	1[a]	2 and 3[b]	1[a]	2 and 3[b]	1[a]	2 and 3[b]
7	63.6	84.3	63.9	94.3	45.3	84.5	35.3	78.0
14	85.2	92.1	73.3	95.9	53.6	90.5	44.1	82.0
30	94.3	98.4	80.2	100.0	67.2	94.0	82.4	88.0
Females not detected in estrus, %	5.7	1.6	19.8	0	32.8	6.0	17.6	12.0

[a]First litter.

Table 3—Number of females that were culled from the breeding herd as a result of death, lameness, failure to maintain pregnancy and other criteria

Breed	No. gilts farrowing	Criteria for leaving herd during three farrowings			
		Died	Lame	Failed to maintain pregnancy	Other
Large White	93	4	4	18	1
Landrace	92	4	8	5	1
Yorkshire	69	3	2	2	0
Chester White	51	9	1	10	1

Follicle Development and Return to Estrus in the Postpartum Sow

James H. Killen, J. Joe Ford, and Ronald K. Christenson[1]

Introduction

The sow's swift return to estrus and conception after farrowing is a key ingredient in efficient pork production. Theoretically, a sow could produce a litter every 152 days or 2.5 litters per yr after attaining puberty at about 200 days of age. In actuality, few pork producers achieve this level of performance in the majority of their herds. Failure to achieve postpartum estrus is the greatest single factor (20.3%) causing sows to be culled (see Maurer article, this publication). Postpartum return to estrus is the result of complex interactions between nutrition, breed, season, and other factors. Regardless of how these factors combine to allow resumption of estrus, failure of this process results in lack of growth of ovarian follicles. Follicle growth, estrus, and ovulation are events that must occur in order and synchrony. In addition to producing specialized gametes (ovum), developing follicles and other ovarian tissues produce hormones that work in concert with pituitary hormones to synchronize events leading to estrus and ovulation.

In some sows, weaning after 21 days postpartum will initiate an increase in the number of ovarian follicles and growth in follicle size within 4 days. Also, the removal of one ovary (unilateral ovariectomy) will trigger compensatory ovarian hypertrophy in the remaining ovary to achieve ovulation rate similar to an unaltered sow without affecting weaning to estrus interval. We can utilize the weaned sow and unilateral ovariectomy procedure to study the effect of hormone changes at the ovarian level on postpartum reproduction (i.e. ovulation rate and weaning to estrus interval).

The objective of this experiment was to characterize changes in steroid hormone concentrations in developing follicles during the period immediately postweaning in sows. More specifically, hormone concentration in follicular fluid from developing follicles and blood from the ovarian vein were analyzed in sows attaining estrus within 10 days postweaning.

Procedure

Second-litter crossbred sows were used to study postweaning changes in steroids (estradiol, testosterone, and progesterone) from follicular fluid and ovarian venous blood samples. At 28 to 32 days, postpartum sows were removed from their litters and exposed to a mature boar for 15 min. After initial exposure, estrus was monitored daily. Fifty-three sows were assigned to a nonsurgical control group. Under general anesthesia unilateral ovariectomy was performed on 47 sows at 0, 6, 12, 18, 24, or 48 hr postweaning. Blood samples were collected from the ovarian and jugular (general circulation) veins at surgery. Ovaries were weighed and the number of small (1-<4 mm), medium (4-6 mm) and large (>6 mm) follicles was recorded. Follicular fluid from small and medium follicles was pooled within size class from each ovary and collected individually from large follicles. Both follicular fluid and ovarian venous blood were analyzed for estradiol, testosterone, and progesterone. At slaughter (2 to 3 wk postweaning), the remaining ovary was removed, and number of CL was noted to determine ovulation rate.

Results

Weaning to estrous interval (avg = 5 days) and CL number were similar for all treatments (93% of the animals achieved estrus within 10 days). The number of small and medium follicles was similar over all treatments. Large follicles were not found before 18 to 24 hr postweaning. In small follicles, the increase in steroid concentration was slight (Fig. 1). In medium follicles, progesterone increased by 6 hr, estradiol increased by 12 hr, and testosterone increased by 48 hr, as illustrated in Figure 1. A similar pattern was evident but concentration was 50-fold less for progesterone in ovarian venous blood (Fig. 2). Interestingly, the pattern of progesterone secretion in follicular fluid or ovarian venous blood was not evident in jugular blood (Fig. 2).

It can be concluded from these results that postweaning follicle growth and accompanying steroid changes occur rapidly (within 6 hr) postweaning and that medium follicles appear to be the major source of ovarian steroids that are secreted during the early stages of follicular growth. It is also evident that peripheral blood samples do not always reflect changes occurring at the ovarian level. Finally, the unilateral ovariectomy procedure combined with the weaned sow appears to be a useful model for the study of follicle growth without altering subsequent reproduction. Additional postweaning studies with both anestrous and estrous sows may lead to management practices that reduce the incidence of postpartum anestrus.

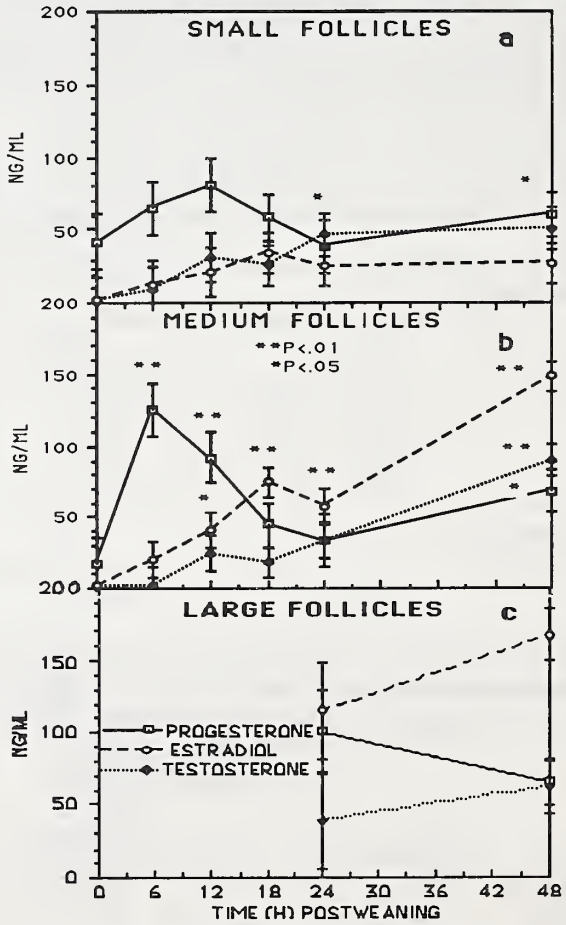

Figure 1—Hormone concentrations in small (a), medium (b), and large porcine follicles postweaning.

[1]Killen is a research affiliate, Ford is a research physiologist, and Christenson is the research leader, Reproduction Unit, MARC.

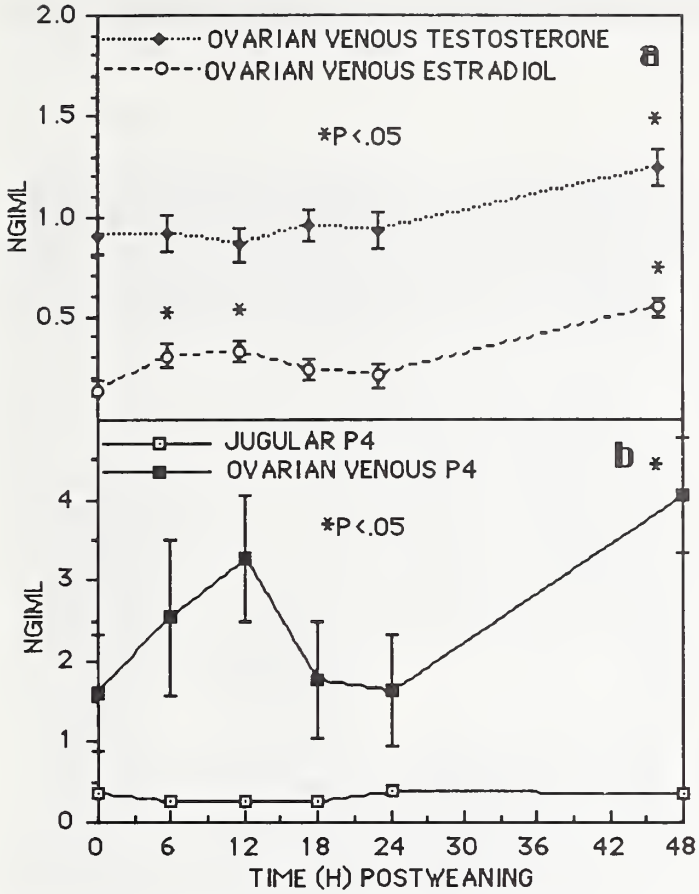

Figure 2—Ovarian venous testosterone and estradiol (a) and ovarian venous and jugular progesterone (P4, b) in porcine blood postweaning.

Regulation by Follicle Stimulating Hormone of the Enzyme That Controls Progesterone Production by Ovarian Granulosa Cells

George W. Mulheron and J. Joe Ford[1]

Introduction

Growth of ovarian follicles, ovulation, and maintenance of pregnancy are critically regulated by steroid hormones. The steroids (progestogens, androgens, and estrogens) are produced by the ovary in response to many factors, but the gonadotropic hormones from the anterior pituitary gland, follicle-stimulating hormone (FSH) and luteinizing hormone (LH), are primary regulators of ovarian steroid production. The conversion of cholesterol into steroid hormones is regulated by a class of oxidative enzymes called cytochrome p-450's. The rate-limiting cytochrome p-450 enzyme for steroid production is cholesterol side-chain cleavage (CSCC) which is responsible for converting cholesterol to progesterone. When granulosa cells are removed from ovarian follicles and grown in culture for a few days, they respond to FSH by producing large quantities of progesterone. The course of events within a cell that leads to production of a particular protein (in our case, CSCC enzyme) is transfer of information from the DNA of the gene of interest to messenger RNA (mRNA). This specific mRNA then directs the sequence in which amino acids are assembled into protein. The present study was designed to determine if FSH-stimulated progesterone production by porcine granulosa cells, in culture, is correlated with production of mRNA for CSCC enzyme. The ability to detect changes in the amount of CSCC mRNA in granulosa cells with a cDNA probe for CSCC enzyme enables us to examine regulation of this rate-limiting enzyme at the level of the gene. Through use of these new techniques of molecular biology, we will gain better understanding of how ovulation rate is controlled and how pregnancy is maintained. The goal of this research is to ultimately develop techniques that will improve reproductive performance of swine.

Procedure

Granulosa cells were isolated from small ovarian follicles collected at slaughter from postpubertal gilts and sows. Cells were cultured for 48 or 96 hr in the presence of 0, 50, or 200 ng/ml of porcine FSH. Culture media and cells were collected at each time and dose and assayed for progesterone and CSCC mRNA concentrations. A cDNA probe (1,000 base pairs in length) was isolated from testes of young pigs, cloned, and used to determine the concentration of CSCC mRNA in granulosa cells.

Results

CSCC mRNA concentration was both FSH dose- (Fig.1) and culture time-dependent (Fig. 2). Furthermore, CSCC mRNA accumulation was correlated ($r = .55$, $P < 0.01$) with progesterone production. From these results, we conclude that FSH stimulates progesterone production in porcine granulosa cells by increasing the concentration of CSCC mRNA. Furthermore, porcine granulosa cell cultures are an excellent model to study regulation, at the molecular level, of those enzymes that control steroid production in ovarian follicles. Further use of the molecular techniques that were developed during this research allows us to investigate how factors in addition to FSH affect steroid hormone production by granulosa cells and how these factors interact to influence growth and development of ovarian follicles.

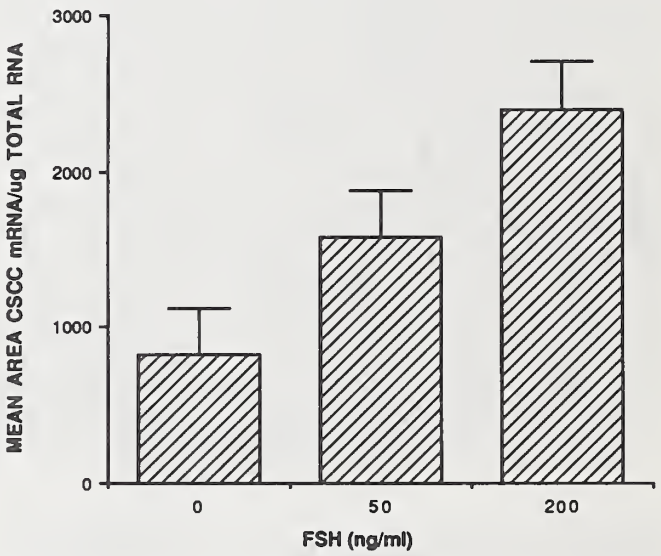

Figure 1—FSH dose-dependent stimulation of CSCC mRNA accumulation by porcine granulosa cells ($P < .01$).

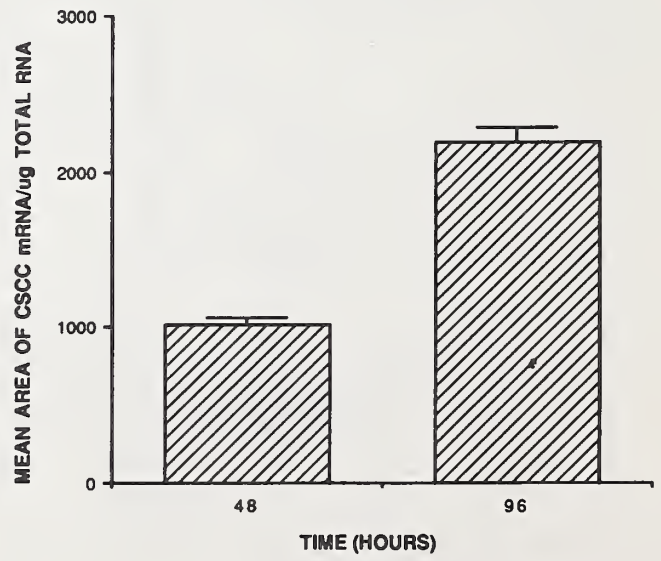

Figure 2—Effect of culture time on granulosa cell accumulation of CSCC mRNA ($P < .01$).

[1]Mulheron is a research associate and Ford is a research physiologist, Reproduction Unit, MARC.

Copper and Clinoptilolite Supplementation to Diets for Growing Pigs

Wilson G. Pond, Jong-Tseng Yen, and Vincent H. Varel[1,2]

Introduction

The potential benefit of dietary supplementation of swine with clinoptilolite has been hypothesized, and experimental data documenting improved wt gain and efficiency of feed utilization under some conditions have been reported. Geographic source and purity of dietary clinoptilolite appear to affect the wt gain response of swine. Clinoptilolite, by virtue of its cation selectivity properties, protects sheep and rats against ammonia toxicity, pigs and rats against cadmium (Cd) toxicity, and rats against lead toxicity. We are unaware of information on the effect of dietary clinoptilolite on copper (Cu) absorption and tissue storage in animals. High levels of dietary Cu (125 to 250 ppm) promote wt gain of growing swine and are used routinely in the United Kingdom for this purpose. Occasional incidents of toxicity in swine fed high Cu diets have been reported. The safety of Cu as a growth promotant in swine could be enhanced if its toxicity could be reduced by clinoptilolite.

The present experiment was done to determine the effectiveness of Cu and clinoptilolite added to the diet singly or in combination on wt gain, organ wt, and liver mineral concentrations of growing swine.

Procedure

Forty-eight crossbred (Chester White x Landrace x Large White x Yorkshire) female weanling pigs were assigned within wt groups (replicates) to the four diets shown in Table 1. Properties and composition of the clinoptilolite used (clinoptilolite provided by East-West Minerals, San Francisco, California) are described in the original report of the work. The diets were fed in a factorial arrangement of treatments (0 and 250 ppm Cu and 0 and 2% clinoptilolite; Cli). Pigs were penned individually in a slotted-concrete floor enclosed building with temperature (70°F), light (12 hr light:12 hr dark), and ventilation control. Their respective diets were fed *ad libitum* from wooden self feeders for 8 wk. Body wt and feed consumption of each pig were recorded biweekly. Blood was sampled from the anterior vena cava of each pig on days 0, 28, and 56 for determination of hematocrit. On day 56, six pigs fed each diet were slaughtered. Liver, kidney, heart, and empty stomach wt were recorded, and pH of the contents of stomach, cecum, colon, and urinary bladder were measured. Cross-sectional areas of the longissimus muscle and of the subcutaneous fat at the 10th-11th rib interface were calculated from acetate paper tracings by planimetric measurement.

Results

The effects of supplemental Cu and Cli fed singly and in combination on body wt, daily gain, daily feed, and gain:feed ratio are summarized in Table 2. Daily wt gain was less in pigs fed the basal diet (B) than in those fed diets supplemented with Cu, Cli, or both (B < Cu = Cu + Cli < Cli). Daily wt gain was 10, 11, and 14% greater in pigs fed Cu, Cu + Cli, and Cli alone, respectively, than in pigs fed the basal diet.

Daily feed intake was increased by Cu or Cli fed singly or together (B < Cu < Cu + Cli < Cli alone), and gain:feed ratio was improved to a similar degree by either additive alone or by the two combined (B < Cu = Cu + Cli = Cli). There were no Cu x Cli interactions for any of the gain and feed traits.

The improved wt gain and efficiency of feed utilization in the presence of 250 ppm added Cu agrees with many previous observations in growing pigs. The response to supplemental Cli agrees with observations of Yugoslavian and Soviet scientists who used Cli from a different deposit than that used in the present experiment. The Cli used here was obtained from a tuff of high purity in Death Valley Junction, California, and produced a clear positive effect on wt gain and efficiency of feed utilization compared with the inconsistent responses reported earlier in pigs fed Cli from other sources. The superior wt gain responses to Cli in this experiment compared with that in previous published experiments from this laboratory may have been due to one or more of the following factors: greater ion-exchange capacity; greater purity of the sample used here; different particle size (-35 mesh in this experiment compared with samples ranging from -50 mesh to granular in previous work); to a more optimum ratio of mineral elements in the source used; the selection of a more nearly optimum supplemental level (2% here *vs* 3 or 5 to 10% in previous work at MARC, respectively).

There was no evidence of toxicity in any of the pigs fed 250 ppm Cu either in the presence or absence of Cli. The similar daily wt gain and gain:feed ratio of pigs fed Cu or Cu-plus-Cli fails to provide evidence for either a beneficial or detrimental effect of dietary Cli on the response to Cu supplementation. Copper and Cli added to the diet at 250 ppm and 2%, respectively, however, appear to produce a similar animal growth and feed response, but there may be a different mode of action. The known inhibitory action of Cu on urease activity in the gastrointestinal tract is a possible explanation for its growth promoting action in animals, in agreement with the theory that selective reduction in urease-producing microflora is associated with a reduction in release of ammonia, a known cell toxicant, by antimicrobial agents. However, Cli supplementation of the diet does not appear to affect ureolytic bacteria or urease production in the colon of growing swine. If Cli exerts its beneficial effect on animal growth through its ammonium-ion-exchange capacity, whereby ammonium-ion is adsorbed to the zeolite binding sites in the small intestine and later released in the colon, the effects of Cu and of Cli may be similar to the extent that both may reduce ammonium-ion concentrations reaching the intestinal mucosal cells for metabolism or absorption. The cation exchange capacity of Cli used, added at 2% of the diet, appeared not to be sufficiently high to reduce the growth-promoting effect of Cu or to affect Cu storage in the liver.

Absolute liver, kidney, heart, and stomach wt were unaffected by diet, but relative liver wt (% of body wt) was less in pigs fed Cu or Cli or both than in pigs fed the basal diet. Relative kidney wt were reduced by Cli. The physiological basis for this reduction is unclear, but changes in nitrogen metabolism associated with differences in amounts of ammonia processed by intestinal epithelium, liver, and kidney may have occurred in the presence of Cu or Cli. This may occur as a result of (1) reduced urease activity in the presence of Cu, or (2) as a result of adsorption of ammonium-ion to the ion exchange site of Cli in the upper gastrointestinal tract at the site of absorption in the lower tract. The reduction in relative mass of liver and kidneys, two metabolically active visceral organs, would allow diversion of nutrients to growth of other body tissues. The cross-sectional area of the longissimus muscle was greater in pigs fed Cli than in pigs fed the basal diet, but,

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[1]Pond is the research leader, Yen is a research animal scientist, and Varel is a microbiologist, Nutrition Unit, MARC.

[2]The full report of this work was published in Nutrition Reports International 37:795-803, 1988.

when expressed as muscle area per unit body wt, the difference disappeared. Thus, the greater muscle area was a function of greater body size and was not due to a change in relative muscle mass due to Cli.

Values for pH of stomach, colon, cecum, and urinary bladder were not affected by diet. Concentration of ammonium-ion and consequent ammonia toxicity is increased with high pH of lumen contents. If Cli binds cations in the intestinal lumen sufficiently to interfere with buffering capacity, an increase in pH of lumen contents would be expected to alter ammonium-ion absorption and perhaps affect the response to supplemental dietary Cu. The addition of 2% Cli to the diet apparently was not associated with changes in buffering capacity sufficient to affect pH of gut contents or of urine.

Liver Cu was increased by supplemental Cu and tended to increase further in the presence of Cli, although not significantly. The effect of Cli on Cu absorption may be related to the molar ratio of Cu to Cli in the diet as noted for ammonium ion and Cli in sheep. Liver zinc was increased and liver iron decreased by supplemental Cu, but neither was affected by Cli. Liver manganese, aluminum, calcium, phosphorus, sodium, and magnesium were unaffected by diet. Liver potassium (K) was decreased by Cli, but was unaffected by Cu. The biological importance of this effect is unclear; the high K-binding affinity of Cli at the pH of the small intestinal tract may have reduced K uptake by the liver.

The effects of dietary Cu and Cli supplementation on bacterial populations in the colon at day 56 are summarized in Table 3. No differences were observed in total colony counts, in agreement with previous work. Ureolytic bacterial counts were lower in the presence of Cu although not significantly so, except with added Cli. Urease activity tended to be lower in the colon of Cu-supplemented pigs, but the difference was not significant. The trends observed in the present experiment agree with results reported previously in pigs fed diets containing 125 ppm Cu for 14 wk.

We conclude that the addition of 250 ppm of Cu as copper sulfate or of 2% Cli, with the physical and chemical properties of that used in the present experiment, improved wt gain of growing swine fed a corn-soybean meal-type diet *ad libitum*. The mode of action is unclear, but the smaller relative liver and kidney wt of animals fed supplemented diets may have allowed utilization of a greater percentage of ingested nutrients for growth of non-visceral tissues. There appeared to be no beneficial interaction between Cu and Cli in any of the responses observed.

Table 1—Composition of diets

Ingredients	Basal	B + 250 ppm Cu	B + 2% Cli	B + Cu + Cli
Corn, No. 2 yellow	76.5	76.4	74.5	74.4
Soybean meal	19.6	19.6	19.6	19.6
Dicalcium phosphate	2.4	2.4	2.4	2.4
Ground limestone	.5	.5	.5	.5
Iodized salt	.4	.4	.4	.4
Vitamin premix[a]	.2	.2	.2	.2
Trace mineral premix[b]	.2	.2	.2	.2
Choline chloride	.2	.2	.2	.2
Copper sulfate .5H_2O[c]	—	.1	—	.1
Clinoptilolite[d]	—	—	2.0	2.0
Total, %	100.0	100.0	100.0	100.0

[a]Vitamin premix supplied the following vitamins/lb of diet: A, 2,400 I.U.; D_3, 320 I.U.; E, 16 I.U.; K, 1.6 mg menadione; B_{12}, 12 mcg; riboflavin, 2.4 mg; niacin, 12.8 mg; d-pantothenic acid, 9.6 mg; biotin, 40 mcg; thiamine, 1.0 mg.

[b]Supplied the following minerals in (ppm) of diet: Cu, 10; iron (as $FeSO_4 \cdot 7H_2O$), 160; Mn (as $MnSO_4$), 20; zinc (as ZnO), 100.

[c]$CuSO_4 \cdot 5H_2O$ added at 0.1% of diet provides 250 ppm Cu added to complete diet (mol wt = 250; Cu atomic wt = 63.5 = 25%; therefore, .1% supplies about 250 ppm Cu).

[d]Clinoptilolite from California-Nevada tuff.

Table 2—Effect of copper (Cu) and clinoptilolite (Cli) alone and in combination on body weight, average daily gain (ADG), and gain:feed (G:F) of growing pigs[a]

Item	Diet			
	Basal (B)	B + Cu[b]	B + Cli[c]	B + Cu + Cli
No. of pigs	12	12	12	12
ADG, lb	1.41	1.55	1.61	1.56
Avg daily feed, lb	3.77	3.92	4.24	4.05
Gain:feed ratio, lb/lb	.374	.400	.385	.395

[a]56-day experiment.

[b]250 ppm Cu as $CuSO_4 \cdot 5H_2O$.

[c]2% clinoptilolite from California-Nevada tuff.

Table 3—Effect of dietary copper (Cu) and clinoptilolite (Cli) on bacterial counts, urease activity, ureolytic bacteria, and ammonia-N in colon samples from growing pigs[a]

Item	Diet			
	Basal (B)	B + Cu[b]	B + Cli[c]	B + Cu + Cli
No. of pigs	6	6	6	6
Total colon counts, 10^{10}·g dry wt^{-1}	15.6	13.9	12.5	13.1
Ureolytic bacteria, percent of total	10.8	7.9	11.3	4.2
Urease activity, mg NH_3·g dry wt^{-1}	1.04	.82	1.44	.78
Ammonia, mg·g dry wt^{-1}	8.9	8.9	9.3	7.9

[a]56-day experiment.

[b]250 ppm copper as $CuSO_4 \cdot 5H_2O$.

[c]2% clinoptilolite from California-Nevada tuff.

Response of Nonpregnant *Versus* Pregnant Gilts and Their Fetuses to Severe Feed Restriction

Wilson G. Pond and Jong-Tseng Yen[1,2]

Introduction

Severe energy restriction during gestation reduces individual pig birth wt. Starvation for 40 days in mid or late gestation reduces birth wt, but starvation for the last 7 or 21 days of gestation has no effect on birth wt or survival in swine. Prolonged severe feed restriction to 2,000 kcal digestible energy (DE) daily [one-third of National Research Council (NRC) recommendations] during the first two-thirds or last two-thirds of pregnancy produced the expected reduction in piglet birth wt and appeared to result in prolonged inhibition of postnatal body wt gain and fat accretion. Such a feeding regimen limits the intake of all nutrients in the diet to one-third of levels consumed by control animals. We are unaware of published reports of the effects of feed restriction to 2,000 kcal DE daily throughout pregnancy in crossbred commercial primiparous swine on reproduction and fetal development. Pregnancy results in partitioning of nutrients to protect the developing fetus. Endocrine controls of nutrient partitioning during pregnancy have been described, but the roles of the maternal and fetal endocrine systems in affecting these changes in swine are essentially unknown. The magnitude of change in body composition of the dam and proportional wt of maternal and fetal tissues in response to severe maternal feed restriction are not clearly defined.

The purposes of this experiment were to test the hypothesis that normal pregnancy occurs in primiparous swine restricted to one-third of NRC-recommended feed allowance throughout gestation and to determine the effects of this feeding regimen on maternal carcass measurements and fetal growth.

Procedure

Crossbred (Chester White x Landrace x Large White x Yorkshire) first-litter gilts 7 to 8 mo of age and weighing 231 lb were fed a standard finishing diet, *ad libitum*, until breeding and assigned on the day of mating to one of two dietary treatments: 1) adequate diet (6,000 kcal DE daily), or 2) severe diet restriction (2,000 kcal DE daily). A nonpregnant littermate to each pregnant gilt was matched by body wt and assigned to the same diet treatment. The diet was a standard corn-soybean meal-type gestation diet containing 14% protein, 1.0% Ca, and .8% P and fed in meal form once daily. All gilts were kept in individual stalls with concrete slatted floors in a light- and temperature-controlled (12 hr light, 12 hr dark; 72°F) well-ventilated building. Dietary treatments were continued to slaughter at day 84 or 106 to 112 days (hereafter referred to as 108 days) of pregnancy. Nonpregnant gilts were slaughtered with their pregnant littermates on the assigned day.

Body wt and ultrasonically determined backfat thickness 2 inches off the dorsal midline at the first rib, last rib, and last lumbar vertebra were recorded at 3-wk intervals throughout the experiment except for backfat at day 84 in gilts slaughtered at day 84 (backfat starting at 3 wk). At day 84, eight gilts from each treatment group (eight pregnant and eight nonpregnant fed 6,000 or 2,000 kcal DE daily) were slaughtered. Reproductive and gastrointestinal tracts were removed within 15 min after slaughter. Chilled carcass wt, carcass length, and wt of trimmed ham, loin, Boston butt, picnic, and belly were recorded. All remaining gilts (nine pregnant and nine nonpregnant gilts fed 6,000 or 2,000 kcal DE daily) were slaughtered at day 108 for the same measurements. Stomach, small intestine, and cecum-colon of each gilt were emptied and weighed. Reproductive tract of each gilt was removed, and ovaries and the remainder of the tract (uterus, cervix, vagina) of nonpregnant gilts were weighed. The reproductive tract of pregnant gilts was handled similarly, except that after weighing the unopened tract minus ovaries, all fetuses in each uterine horn were removed after obtaining a blood sample from the umbilical artery, and weighed individually; empty uterus-cervix-vagina plus placentas of each gilt were weighed, and the difference in wt from that of the unopened tract was assumed to be allantoic, amniotic, and uterine fluids. Fetal umbilical artery blood was collected within 20 min after gilt stunning (fetal hearts still beating) into heparinized, Ca fluoride-containing tubes and placed on ice, centrifuged, and the plasma frozen at -40°F until analyzed for glucose and growth hormone. Brain cortex, liver, kidneys, gastrointestinal tract, and pancreas were weighed from eight randomly selected fetuses from each litter (or all fetuses from litters with less than eight piglets).

Results

As expected, body wt gain of gilts fed 6,000 kcal DE daily (C) was greater than that of gilts fed 2,000 kcal (R); pregnant gilts were heavier than nonpregnant gilts. The difference in wt between C and R gilts increased with time, resulting in a feed intake x time interaction; body wt at day 108 was greater than at day 84. Body wt at day 108 of pregnant gilts was 330 lb for C and 242 lb for R; that of nonpregnant gilts was 297 lb for C and 211 lb for R. Backfat depth was less in R than in C gilts. Mean overall backfat over the first rib was 0.54 inches, over the last rib 0.40 inches, and over the last lumbar vertebra 0.44 inches. In all cases, there was an effect of feed intake and a feed intake x pregnancy interaction, suggesting that any one of the three backfat measurements can be used as an index of the effect of feed intake and pregnancy on backfat depth in gilts. Pregnant gilts had less backfat than their nonpregnant littermates when daily feed intake was 6,000 kcal DE (C), but the reverse was true when intake was 2,000 kcal (R), resulting in a feed intake x pregnancy interaction. Backfat of C gilts increased or remained unchanged over time, whereas that of R gilts declined, resulting in a feed intake x time interaction.

Carcass measurements are summarized in Table 1. Chilled carcass wt of C gilts was greater than that of R gilts. Pregnancy was associated with a reduction in chilled carcass wt, particularly in C gilts. Carcass length was unaffected by pregnancy but was greater in C than in R gilts. Trimmed loin, picnic, Boston butt, ham, and belly expressed as percentages of live body wt were reduced by pregnancy and were generally less at day 108 than at day 84. There was a day x pregnancy interaction for all wholesale cut traits, resulting from a greater difference between pregnant and nonpregnant gilts at day 108 than at day 84. Trimmed lean cut wt (Boston butt, picnic, loin, ham) expressed as a percentage of carcass wt, was greater in R than in C gilts.

Severe feed restriction reduced absolute wt of stomach, small intestine, cecum-colon, spleen, kidney, and leaf fat. However, when expressed as relative wt (% of body wt), there

[1]Pond is the research leader and Yen is a research animal scientist, Nutrition Unit, MARC.

[2]The full report of this work was published in J. Anim. Sci. 63:472-483, 1986.

was no difference due to feed intake, reflecting proportionate changes in wt of internal organs in response to reduced feed intake of pregnant and nonpregnant swine. Absolute and relative wt of stomach were less at day 108 than at day 84, while the opposite was true for spleen. Relative wt of stomach, cecum-colon, spleen, and kidney, but not of small intestine, were less in pregnant than in nonpregnant gilts; there was no interaction of pregnancy with feed intake on relative wt of any of these organs. Absolute and relative wt of the entire reproductive tract (including fetuses) were greater at day 108 than at day 84 and greater in pregnant than in nonpregnant animals; pregnant R gilts were affected more than pregnant C gilts, but feed restriction had less effect in nonpregnant gilts, resulting in a pregnancy x feed intake interaction. Absolute wt of empty uterus plus placentas from pregnant gilts were less at day 84 than at day 108, but the effect due to feed restriction was not significant. Relative wt followed a similar trend. Absolute wt of leaf fat was reduced by pregnancy but only in C gilts, resulting in a pregnancy x feed intake interaction.

Data on litter size and fetal organ size showed several effects of diet. Absolute body and organ wt was approximately doubled between days 84 and 108. Fetal wt was reduced by maternal feed restriction at days 84 and 108. Fetuses from C dams weighed 2.29 lb at day 108 compared with 2.00 lb for fetuses from R dams. Weight of progeny of R gilts was 87.1% of that of C gilts at day 84 and 86.6% at day 108, showing clearly that severe maternal feed restriction during the first 84 days (before the greatest growth in absolute wt) of fetal life affects fetal development. Absolute wt of liver, kidney, and gastrointestinal tract were reduced by maternal feed restriction, while those of brain cortex and pancreas were unchanged. Relative liver and gastrointestinal tract wt was unaffected by dam treatment; but relative kidney wt was less, and brain cortex wt was greater in fetuses from R than from C gilts. Relative pancreas wt was unchanged by maternal feed restriction. Absolute wt of all organs was increased from days 84 to 108. However, when expressed as relative wt, gastrointestinal tract and liver increased, kidney decreased, and pancreas and cortex were unchanged from days 84 to 108. There were no significant interactions between dam diet and fetal age for either absolute or relative wt of any organ measured.

Data on body wt and on plasma glucose, growth hormone, total protein, and albumin concentration of fetuses from which umbilical artery blood was sampled at day 84 or 108 of fetal age are summarized in Table 2. Plasma glucose was higher at day 108 than at day 84 and was increased by maternal energy restriction at day 108 but not at day 84, resulting in a feed intake x age interaction. Plasma growth hormone concentration was higher in fetuses from R dams than in those from C dams and was lower at day 108 than at day 84, although the difference between fetuses from R *vs* C dams was greater at day 108 than at day 84, resulting in a feed intake x age interaction. Plasma total protein and albumin were higher at day 84 than at day 108 and were reduced by maternal feed restriction. There were no interactions between maternal diet and fetal age for either trait.

Table 1—Effect of level of feed intake and stage of gestation on carcass measurements of pregnant and nonpregnant gilts' daily feed intake[a]

	Daily feed							
	6,000 kcal DE				2,000 kcal DE			
	Day 84		Day 108		Day 84		Day 108	
Trait	No[b]	Yes[c]	No	Yes	No	Yes	No	Yes
No. gilts	8	8	9	9	8	8	9	9
Chilled carcass wt, lb	188	184	188	174	134	134	134	131
Carcass length, in	35.2	35.3	35.3	35.8	33.6	32.8	33.7	33.5
Trimmed ham, % body wt	7.2	6.9	7.3	6.1	7.5	6.9	7.7	6.4
Trimmed loin, % body wt	7.7	7.0	7.0	6.1	7.3	7.0	7.4	6.1
Trimmed picnic, % body wt	3.4	3.2	3.2	2.7	3.4	3.2	3.3	2.8
Trimmed Boston butt, % body wt	3.1	2.8	3.0	2.5	3.0	3.0	3.2	2.7
Trimmed belly, % body wt	3.4	3.1	3.3	2.7	2.7	2.6	2.8	2.3

[a]Least-squares means.
[b]Not pregnant.
[c]Pregnant.

Table 2—Effect of level of maternal feed intake and stage of gestation on fetal plasma glucose and growth hormone concentrations in swine

	Daily feed			
	6,000 kcal DE		2,000 kcal DE	
Trait	Day 84	Day 108	Day 84	Day 108
No. litters	8	8	9	9
No. fetuses	70	76	85	85
Body wt, lb	1.04	2.28	.90	2.00
Plasma glucose, mg/dl	43	157	38	224
Plasma growth hormone ng/ml	289	141	298	184
Plasma protein, g/dl	1.79	1.70	1.74	1.61
Plasma albumin, g/dl	.47	.35	.43	.31

The results of this experiment extend the observation that reproduction in swine can be sustained on a daily intake of 2,000 kcal DE. In the previous experiment, second-litter gilts were fed at this level for two-thirds of pregnancy (first 10 wk or last 11 wk), whereas, in this work, primiparous gilts were fed 2,000 kcal DE daily through day 84 or 108. Pregnant gilts gained more wt than nonpregnant littermates, in agreement with other reports. However, carcass wt, relative wt of trimmed lean cuts, and absolute and relative gastrointestinal tract wt were not increased by pregnancy. Our data do not support the concept of "pregnancy anabolism," but rather are in agreement with the observations of others, who found that the greater wt gain of pregnant animals was attributable mainly to the increase in uterine and mammary tissue.

The reduced fetal wt resulting from severe maternal feed restriction was expected, the data of the present experiment show clearly that feed intake of 2,000 kcal DE daily from day 1 of pregnancy is associated with a large reduction in fetal wt relative to that of control fetuses at day 84, as well as at day 108 of gestation. Even at the higher of the two intakes used in our experiment, pregnant gilts may have been in negative energy balance during the latter part of gestation. Although the percentage of total daily metabolizable energy requirement needed for reproductive tissues appears to increase from 3% at day 50 to 15% at day 110 of gestation, the total energy retained in reproductive tissue represents no more than 10% of the total. The reduction in fetal wt at day 84 for the R gilts and the approximately equal percent reduction at day 108 observed in the present experiment reflects important effects on placental and(or) uterine growth and development by severe maternal feed restriction.

The absolute wt of stomach, small intestine, colon, spleen, and kidney were reduced by severe feed restriction both in pregnant and nonpregnant gilts, but, when expressed as percentage of body wt, pregnant gilts generally had smaller relative organ wt than nonpregnant gilts, providing evidence for partitioning of energy and protein to other tissues, i.e., reproductive and fetal tissues. However, there was no greater trend for reduced relative visceral organ wt in severely restricted than in control gilts, indicating no major repartitioning of nutrient deposition to these tissues in response to severe maternal feed restriction. Backfat thickness, on the other hand, appeared to be affected by pregnancy such that, when feed intake to day 108 was severely restricted, backfat was greater than in nonpregnant littermates; but when intake was at the recommended level backfat was less than in nonpregnant littermates. This phenomenon, coupled with the greater reduction in relative wt of trimmed lean cuts in pregnant than in nonpregnant gilts fed 2,000 kcal DE daily to day 108, suggests a pregnancy-induced repartitioning of energy to maternal depot fat reserves for sustained fetal survival. The endocrine or metabolic control of such an adjustment is unclear.

The data reported herein demonstrate the ability of the primiparous gilt to complete a 108-day gestation period while consuming one-third of NRC-recommended daily feed allowance (2,000 kcal DE), and provide evidence suggesting no anabolic effects of pregnancy other than increased growth of reproductive tissues and perhaps mammary tissues, although the latter response was not measured. Also, the results illustrate that the extent of fetal growth retardation associated with this degree of maternal feed restriction is similar at day 84 to that at day 108 in swine.

Responses of Genetically Obese, Lean, and Contemporary Growing-Finishing Swine to a Corn-Soybean Meal-Based Diet With and Without Supplemental Lysine

Wilson G. Pond and Ted W. Acton[1]

Introduction

The National Research Council (1988) lists the required lysine level of the diet for growing pigs weighing 44 to 77 lb at 0.95% and at 0.75% and 0.60% of the diet for pigs weighing 77 to 132 and 132 to 220 lb, respectively. As genetic selection for leanness has intensified, pigs of contemporary genetic background have a higher body protein content than pigs of previous generations at a given body wt. One might consider the possibility that these selected lean contemporary pigs have a higher total protein and lysine requirement. The availability of genetically obese and lean pigs selected over many generations for high- or low-backfat thickness by USDA scientists at Beltsville, Maryland, in the 1950's and 1960's offers the opportunity to compare the effect of genetically determined body composition on the response to lysine supplementation.

Lysine is accepted as the first limiting amino acid in corn-soybean meal diets fed to swine and may replace some of the soybean meal without sacrificing wt gain or efficiency of feed utilization. Although National Research Council (1988) suggests that diets containing 0.75% lysine for the 44 to 77 lb pig may be adequate, other work suggests that a higher level may be required for optimum performance of pigs of this wt.

This experiment was designed to determine the effect on pig performance of lysine supplementation to a corn-soybean meal-based diet containing crude protein at a level recommended by National Research Council (1988). Performance criteria were daily gain, feed utilization, and backfat thickness. Genetically obese and lean pigs selected for high or low backfat or in contemporary crossbred pigs selected for rapid wt gain and carcass leanness were fed the basal or lysine-supplemented diet from 42 lb body wt to market wt.

Procedure

Two hundred forty weanling pigs (avg wt 42 lb) representing three genetic stocks—obese (O) and lean (L) Duroc-Yorkshire composites descended from lines selected for high and low backfat, respectively, and Chester White x Landrace x Large White x Yorkshire contemporary crossbreds (C)—were used. Each group of 40 pigs within each genotype was assigned randomly within each of two replicate groups of 20 pigs to a basal corn-soybean meal-based diet, or the basal diet supplemented with 0.2% L-lysine monohydrochloride (Table 1). Each group of 20 pigs was fed *ad libitum* from a wooden self-feeder in a concrete-floor pen (6 x 20 ft) in an open-fronted building (20 pigs times three genotypes times two diets times two replicates equal 12 pens totaling 240 pigs). Body wt of each pig was recorded at 0, 4, 8, 12, and 16 wk; feed consumed by each pen of pigs was measured throughout the 16-wk experiment; and backfat of each pig was estimated by ultrasonic measurement taken 1 inch off the midline over the shoulder, midback, and rump (avg of these three measurements) at the end of the 16-wk experiment. Main effects (diet, breed, and replicate) and all interactions were tested by least-squares analysis of variance. Data on daily body wt gain were corrected to constant initial body wt. Individual pig was the experimental unit for daily gain and backfat thickness; pen was the experimental unit for daily feed consumption and gain:feed ratio.

Results

The results are summarized in Table 2. Supplementation of the diet with lysine had no significant effect on daily gain, daily feed, or gain:feed ratio over the 16-wk experiment. Contemporary crossbred (C) pigs had a higher daily gain than obese (O) and lean (L) pigs. Obese pigs and C pigs consumed more feed daily than L pigs, while gain:feed ratio was less in O than in L and C pigs, regardless of lysine supplementation. Mean backfat at 16 wk for pigs fed the basal diet was identical to that for pigs fed the lysine-supplemented diet (columns headed "overall" in Table 2). However, O pigs fed supplemental lysine had less backfat, and L and C pigs fed lysine tended to have more backfat than those fed the basal diet, resulting in a genetics x diet interaction.

The results support the recommendations of the National Research Council (1988) regarding the dietary levels of lysine needed by contemporary pigs selected for rapid and efficient wt gain and for leanness. The large differences among the three genotypes in their wt gain, voluntary feed consumption, and body composition (based on backfat measurements) illustrate clearly the wide diversity for these traits present in the U.S. swine germ plasm pool. The greater feed intake and backfat thickness of O compared with L pigs fits well with the observed advantage in gain:feed ratio of L pigs over O pigs.

If one assumes that lysine is required at a constant percentage of the dietary protein, then supplementation of lysine to a diet consumed by pigs with a low dietary protein requirement relative to that of contemporary lean pigs (O *vs* L or C) would result in a differential growth response. The failure of either L or C pigs to show a wt gain response to supplemental lysine in this experiment negated the possibility of showing such a differential response.

It is concluded that increasing the lysine content of a corn-soybean meal diet from 0.89% to 1.02% of the diet from 44 to about 154 lb liveweight and from 0.68% to 0.80% from about 154 lb to slaughter wt has no effect on daily wt gain or feed consumed or on gain:feed ratio of crossbred (Chester White x Landrace x Large White x Yorkshire) contemporary pigs selected for rapid wt gain and carcass leanness.

Summary

The diets were calculated to contain 16% crude protein for the first 12 wk and 13% crude protein from 12 wk to the end of the 16-wk experiment.

Supplemental lysine had no effect on daily gain, daily feed, or gain:feed ratio. Mean backfat at 16 wk for pigs fed the basal diet was identical to that for pigs fed the lysine-supplemented diet. Contemporary pigs had higher daily gain than lean and obese pigs; obese pigs had a lower gain:feed ratio and had more than twice as great backfat thickness as lean and contemporary pigs. The dramatic effects of selection for increased backfat thickness and effects on associated traits, including a decrease in efficiency of feed utilization, are clearly illustrated. There appear to be no major interactions between genetic background and lysine content of the diet with respect to body wt gain and feed consumption in swine.

[1]Pond is the research leader, Nutrition Unit; Acton is swine operations manager, MARC.

Table 1—Composition of diets

Ingredient	First 12 wk		12 wk to slaughter	
	Basal %	Basal + lysine %	Basal %	Basal + lysine %
Corn	76.3	76.1	81.9	81.7
Soybean meal	19.6	19.6	14.0	14.0
Dicalcium phosphate	2.4	2.4	2.4	2.4
Limestone	0.5	0.5	0.5	0.5
Iodized salt	0.4	0.4	0.4	0.4
Vitamin premix	0.2	0.2	0.2	0.2
Choline chloride	0.2	0.2	0.2	0.2
Trace mineral	0.4	0.4	0.4	0.4
L-lysine HCl	—	0.2	—	0.2
Total, %	100.0	100.0	100.0	100.0
Analyzed values:				
A&L Mid-West Agri. Labs., Inc.				
Moisture, %	9.1	8.4	10.5	11.6
Crude protein, %	15.9	16.7	12.5	12.9
Lysine, %	.89	1.02	.68	.80
Lysine, % of protein	5.8	6.3	5.2	5.6

Table 2—Effect of supplemental lysine on performance of genetically obese, lean, and contemporary growing-finishing swine[a]

Diet (D)	Basal				Basal plus lysine			
Genotype (G):	O[b]	L[c]	C[d]	Overall	O	L	C	Overall
Daily gain, lb[e]	1.19	1.10	1.41	1.23	1.19	1.18	1.46	1.28
Daily feed, lb	10.9	8.4	10.5	9.9	9.8	8.2	10.4	9.5
Gain:feed ratio	.109	.132	.135	.125	.122	.144	.141	.135
Backfat, in	2.1	.7	.9	1.2	2.0	.7	1.0	1.2

[a]All means are for 20 pigs in each of two replicates fed for 16 wk *ad libitum*.
[b]O = obese.
[c]L = lean.
[d]C = contemporary.
[e]Mean initial weight of obese, lean, and contemporary pigs was 43.6, 39.6, and 44.9 lb, respectively.

Immunization Against Cholecystokinin (CCK) to Increase Appetite and Performance of Swine

Jerome C. Pekas[1]

Introduction

Previous research at MARC demonstrated that swine have the potential to gain body wt at rates 40% greater than that observed on *ad libitum* feeding (Swine Research Progress Report No. 2, p 69). The additional gain and carcass tissue consisted of normal proportions of lean and fat. The previous study involved experimental administrations of a semi-liquid meal directly into the stomach via a gastric fistula at levels distinctly in excess of normal *ad libitum* intake. Greater than normal *ad libitum* intake has been described by the author as "superalimentation". The objective of the study to be described in this report was to attempt to increase food intake voluntarily. The purpose was to attain superalimentation without the need for a surgical fistula or the intense labor required for gastric fistula feeding and, most importantly, to attain superalimentation under conditions which would be practical on the farm. In essence, the goal was to stimulate appetite and thus increase feed intake and growth. Previous attempts to enhance appetite in swine have failed. The author of this report conceived a hypothetical method which has never been tested. Briefly, the hypothesis is that the hormone cholecystokinin, hereafter CCK, is an important part of the normal physiological mechanism to regulate food intake which operates by suppression of appetite. It is known that CCK is released during a meal and accumulates in the blood. There is evidence that these releases suppress food intake by some unknown mechanism. The hypothesis has three parts: 1) that food intake would be increased by suppression of the levels of CCK in blood during eating; 2) that blood CCK levels would be suppressed by serum antibodies; and 3) that serum antibodies would be obtained by immunizing the animals against CCK.

[1]Pekas is a research physiologist, Nutrition Research Unit, MARC.

Procedure

A vaccine was prepared wherein the biologically active fragment of CCK—the C-terminal octapeptide or CCK-8—was linked to a much larger antigenic carrier protein, human serum globulin (hSG). The primary (P) inoculation was administered to the animals by subdermal-subcutaneous injection on day 1 of the study. Three booster inoculations (B1, B2, B3) were similarly administered on days 29, 43, and 64. The CCK-8 antigen was administered to one group of animals (CCK-8); control animals (hSG) received a vaccine which contained only the antigenic carrier protein, hSG. The study involved 24 growing animals (avg 75 days of age and 56.3 lb body wt) randomly assigned to the two groups (CCK-8 *vs* hSG) and to 12 pens (2 pigs/pen). Both groups were fed *ad libitum* a conventional corn-soybean swine diet formulated to provide 18% crude protein. Feed consumption and gain were observed through day 77. Feed intake was measured daily and corrected for estimated feed wastage; body wt was measured weekly. Blood samples were drawn on days 1, 15, 29, 43, 64, and 78 for assay of the level of serum antibodies. Serum antibodies were estimated from the percentage of radiolabelled CCK-8 bound by serum diluted 1:181.

Results

The levels of antibodies in the serum are illustrated in Figure 1. Antibodies were detectable by day 15, and the avg percent binding was greatest on day 43. Thus antibodies were developing during the first phase (days 1 through 42) and remained near the peak level during the second phase (days 43 through 77). Feed intake (Fig. 2) and wt gain (Fig. 3) were compared statistically during the total 77-day period (Table 1). Each measurement of performance was improved by CCK immunization; the gain efficiency response was not statistically significant, however. The avg CCK animal consumed 22.5 lb more feed, was 12.6 lb heavier, and gained 11.0 lb more wt than the avg hSG animal. Simple linear regression analyses (Table 2) of the responses during the second phase indicated that, for each percentage unit increase of serum binding capacity, gain increased .168 lb. For example, if serum binding capacity was 50%, gain would be 8.4 lb more than at 0% binding. The regression equation for gain accounted for 34% of the variation of gain in these animals. In contrast, the regression coefficients (slope) for feed intake and gain efficiency were not statistically significant.

In summary, these swine were successfully immunized. Production of antibodies against cholecystokinin was associated with an increase of performance. Feed intake was increased 8.2%, and gain increased 10.6% during the 35-day period in which serum binding capacity of CCK was highest. The evidence suggests that it may be feasible to increase voluntary feed intake and that appetite may be enhanced by binding and neutralizing CCK levels in the blood with antibodies induced by immunization against CCK.

Table 1—Summary of body wt, food intake, gain, gain efficiency, and ^{125}-I CCK-8 binding of serum; means, for the overall 77-day study

Variable[a]	Treatment hSG	Treatment CCK	Response (CCK-hSG)	Prob. (>F)
Final body wt (FBW)	195.1	208.8	+13.7	.01
Empty body wt (EBW)	187.4	200.0	+12.6	.01
Food intake (FI)	416.4	438.9	+22.5	.08
Gain (GN)	132.9	144.0	+11.1	.006
Gain efficiency (GE)	.320	.328	+ .008	.34
^{125}-I-CCK-8 bound	0.6	18.9	+17.1	.0001

[a]Means for FBW, EBW, FI, and GN are expressed as lb/animal; GE as lb GN/lb FI; ^{125}-I-CCK-8 bound as % of radiotracer bound at 1:181 dilution of serum. EBW computed as FBW minus ingesta recovered in gastrointestinal tract. Statistical comparisons were computed using the total value for each pen (six pens/treatment group; two pigs/pen).

Table 2—Regression analyses of relationships between gain and food intake variables and CCK-8 antibody titer during the second phase (days 43 to 77)

Dependent variables[a]	Corr. coeff. (R^2)	Intercept Coeff.	Intercept Prob.	Slope Coeff.	Slope Prob.
Food intake (FI)	.2035	207.2	.0001	.430	.141
Gain (GN)	.3422	59.7	.0001	.168	.045
Gain efficiency (GE)	.0556	.288	.0001	.000202	.460

[a]See Table 1 for description of units, abbreviations, and computations of variables. Independent variable was the pen mean of ^{125}-I-CCK-8 bound which consisted of six assays/pen (two pigs; three assays/pig—days 43, 64, 78).

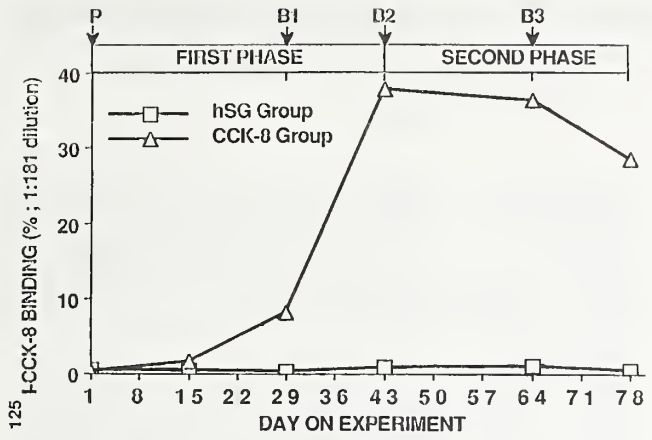

Figure 1—Graphic summary of the avg (12 animals from six pens) level of cholecystokinin antibodies in serum over the course of the 77-day study. Results are expressed as percentage of ^{125}I-CCK-8 tracer (0.45 pg per assay; sp. act ~ 30 Ci/mmol) bound by serum diluted 1:181 and corrected for nonspecific binding. First and second phases represent days 1 to 42 and days 43 to 77, respectively. P designates day of primary innoculation; B designates day of each of three booster inoculations. hSG designates the protein carrier control group; CCK-8 designates the CCK-8 conjugated protein group.

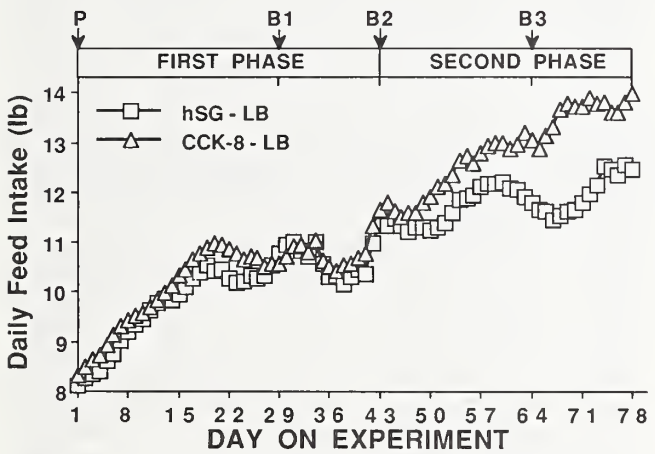

Figure 2—Graphic summary of avg daily food intake (lb per pen per day; two pigs per pen) over the course of the study. See Figure 1 legend for additional explanation and Table 1 for statistical analyses of responses.

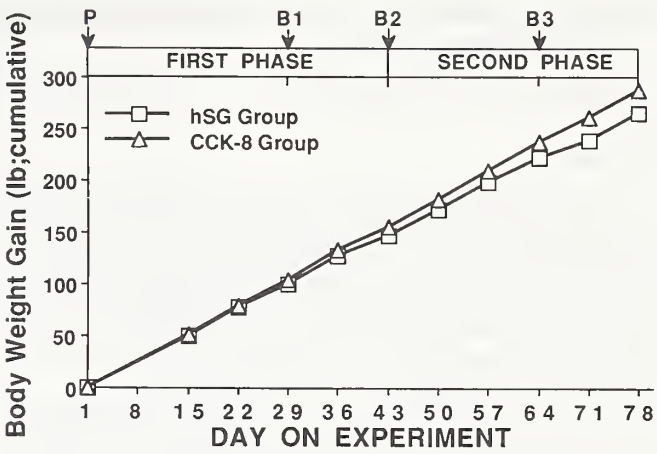

Figure 3—Graphic summary of the cumulative body wt gain (lb per pen; two pigs per pen) over the course of the study. See Figure 1 legend for additional explanations and Table 1 for statistical analyses of responses.

Effect of Dietary Supplementation with Vitamin C or Carbadox on Weanling Pigs Subjected to Crowding Stress

Jong-Tseng Yen and Wilson G. Pond[1]

Introduction

It has been suggested that, under certain conditions, pigs may not be able to synthesize enough vitamin C to meet their needs. Dietary vitamin C supplementation prevents the post-weaning decline of plasma vitamin C concentration and occasionally improves the wt gain of pigs. Supplementation of carbadox, a synthetic growth-promoting antimicrobial agent, also increased plasma vitamin C concentration after a short lag period and consistently improved wt gain.

In mice, crowding resulted in a decrease of vitamin C level in adrenal glands. Crowding also reduced the wt gain of weanling pigs. However, the effect of crowding on vitamin C concentrations in plasma and adrenal glands in weanling pigs is unknown.

The purpose of this study was to determine the effect of crowding on wt gain, feed intake, efficiency of feed utilization, concentrations of vitamin C in plasma and adrenal glands, and wt of several stress related organs, such as adrenal gland, spleen, and thymus; and to examine whether supplemental vitamin C or carbadox would alleviate the stress caused by crowding in weanling pigs.

Procedure

We conducted two trials. In each trial, there were two levels of floor space allowance (2.8 and 1.4 ft^2/pig) and three dietary treatments (basal diet, basal diet + 660 ppm vitamin C, and basal + 55 ppm carbadox). The floor space allowance of 2.8 ft^2/pig can be considered as adequate and normal for pigs in the study because 3 ft^2/pig is the recommended optimal floor space allowance for 25 to 40 lb pigs housed on a slatted floor. The effect of crowding in this study was created by reducing the floor space allowance from 2.8 to 1.4 ft^2/pig. The reduction in floor space allowance was achieved in Trial 1 by doubling the number of pigs per pen from 8 to 16 and in Trial 2 by reducing the size of pens by one-half while maintaining the same number of pigs per pen. The pens measured 3 x 8 ft and had raised expanded-metal floors. Each pen was equipped with an automatic nipple waterer and a five-hole feeder measuring 2.4 ft in length.

The pigs were housed in a temperature-controlled nursery. An 18% protein starter diet was used as the basal diet. Each of the three diets was self-fed to three pens of pigs in each trial. Total number of pigs used were 216 in Trial 1 and 144 in Trial 2. They were weaned between 4 and 5 wk of age, moved immediately to the nursery, and assigned to the treatments. Pig wt and feed consumption were recorded weekly for 4 wk. Blood samples were taken from all pigs in replicates 2 and 3 at the outset of the test and then weekly. On day 29 of the test, four gilts from replicate 2 of each treatment were sacrificed for organ measurements.

Results

Trial 1. As shown in Table 1, crowding weanling pigs by increasing number of pigs per pen from 8 to 16, thus reducing floor space allowance from 2.8 to 1.4 ft^2 per pig, did not significantly affect avg daily gain of pigs up to day 14 of the test. However, when measured on day 28 of the test, crowded pigs had significantly lower daily gain than those not subjected to crowding. The crowded pigs had a significantly lower avg daily feed intake when measured on days 14 and 28 than did the noncrowded pigs. Nevertheless, there was no significant difference in gain:feed ratio between crowded and non-crowded pigs.

Dietary supplementation with carbadox, but not vitamin C, significantly improved daily wt gain and gain:feed of pigs through the entire test period and significantly increased daily feed intake of pigs when measured on day 28. Carbadox supplementation enabled crowding-stressed pigs to obtain levels of feed intake similar to those of noncrowded pigs fed the basal diet and to achieve wt gain and efficiency of feed utilization similar to, or better than, noncrowded basal diet-fed pigs.

Vitamin C supplementation increased plasma vitamin C concentration during the entire test period. Carbadox also increased plasma vitamin C concentration. Crowding the pigs by increasing animal density and reducing floor space allowance did not affect vitamin C concentrations in plasma and adrenal glands. Crowding also had no effect on the wt of adrenal glands, spleen, and thymus. Significantly greater spleen wt was produced by dietary carbadox but not vitamin C.

Trial 2. The response of weanling pigs to crowding from reducing floor space allowance alone and to dietary supplementation of vitamin C or carbadox are summarized in Table 2. In agreement with the results of Trial 1, reducing floor space allowance caused an impaired daily wt gain of pigs. However, contrary to the results of Trial 1, crowding pigs by reducing floor space allowance alone did not significantly decrease feed intake. As a consequence, crowded pigs had significantly lower gain:feed ratio than did noncrowded pigs. These results suggest that the reduced feed intake observed in Trial 1 was caused by greater animal competition for feeder space due to increased animal density, rather than to reduced floor space allowance itself. As in Trial 1, dietary carbadox, but not vitamin C, significantly improved wt gain and feed efficiency of pigs.

In agreement with Trial 1, reducing floor space allowance had no effect on vitamin C concentrations in plasma and adrenal glands or on wt of adrenal glands, spleen, and thymus. Supplementation with vitamin C produced higher plasma vitamin C concentration. Carbadox supplementation also produced higher vitamin C concentration and greater spleen wt.

On the basis of these two trials, it is concluded that crowding weanling pigs by reducing floor space allowance from 2.8 to 1.4 ft^2 per pig caused a reduction in wt gain. When the reduction of floor space allowance was accomplished by increasing number of pigs per pen, pigs responded with a reduced feed intake due to competition for feeder space with no change in the efficiency of feed conversion. However, when floor space allowance was reduced by changing the size of pen, feed intake of pigs was not affected, but feed efficiency was reduced. The detrimental effect of crowding on wt gain of weanling pigs appears to be unrelated to the metabolism of vitamin C. Supplementation of carbadox, but not vitamin C, improved the performance of crowding-stressed pigs by maintaining a higher level of feed intake and improving feed efficiency.

[1]Yen is a research animal scientist and Pond is the research leader, Nutrition Unit, MARC.

Table 1—Performance, vitamin C concentration in plasma and adrenals, and weights of adrenals, spleen, and thymus of pigs in trial 1

Item	2.8 ft²/pig (8 pigs/pen)			1.4 ft²/pig (16 pigs/pen)		
	Basal	Vit C	Carb	Basal	Vit C	Carb
Avg daily gain, lb[a]						
Days 0-14	.49	.52	.66	.44	.51	.60
Days 0-24	.76	.71	.90	.63	.62	.81
Avg daily feed, lb[a]						
Days 0-14	.92	.91	1.03	.79	.80	.93
Days 0-28	1.51	1.55	1.73	1.28	1.27	1.48
Gain/feed[a]						
Days 0-14	.53	.57	.65	.56	.63	.64
Days 0-28	.50	.46	.54	.49	.49	.54
Plasma vit C, mg/dl[b]						
Initial	1.74	1.71	1.57	1.67	1.63	1.60
Day 14	1.26	1.45	1.36	1.17	1.56	1.43
Day 28	1.35	1.82	1.73	1.40	1.83	1.48
Adrenal vit C, mg/g[c]	2.29	2.28	2.27	2.23	2.28	2.17
Slaughter wt, lb[c]	41.76	35.20	41.08	34.58	34.03	40.93
Adrenal wt, 10^{-3} % body wt[c]	.075	.084	.079	.083	.086	.094
Spleen wt, % body wt[c]	.132	.146	.178	.142	.146	.177
Thymus wt, % body wt[c]	.262	.218	.316	.296	.234	.175

[a]Values are means for three pens of pigs with 16.5 lb avg initial wt and allowed to consume feed *ad libitum* with a five-hole feeder in each pen.

[b]Values are means for 16 or 32 pigs depending on animal density per pen.

[c]Values are means for four pigs per treatment and determined on day 29 of the test.

Table 2—Performance, vitamin C concentration in plasma and adrenals, and weights of adrenals, spleen, and thymus of pigs in trial 2

Item	2.8 ft²/pig (8 pigs/pen)			1.4 ft²/pig (8 pigs/pen)		
	Basal	Vit C	Carb	Basal	Vit C	Carb
Avg daily gain, lb[a]						
Days 0-14	.42	.43	.57	.41	.38	.53
Days 0-24	.66	.71	.85	.60	.56	.77
Avg daily feed, lb[a]						
Days 0-14	.87	.78	.89	.86	.81	.88
Days 0-28	1.40	1.45	1.59	1.35	1.32	1.53
Gain/feed[a]						
Days 0-14	.48	.56	.63	.48	.47	.60
Days 0-28	.47	.49	.53	.45	.43	.50
Plasma vit C, mg/dl[b]						
Initial	1.91	1.88	1.86	1.89	2.09	1.90
Day 14	1.26	1.43	1.41	1.40	1.62	1.66
Day 28	1.39	1.82	1.55	1.58	1.69	1.59
Adrenal vit C, mg/g[c]	2.17	2.16	2.39	2.21	2.18	2.17
Slaughter wt, lb[c]	39.80	41.52	47.31	39.60	34.25	43.56
Adrenal wt, mg/10^{-3}% body wt[c]	.086	.085	.080	.083	.094	.089
Spleen wt, % body wt[c]	.183	.201	.202	.172	.155	.198
Thymus wt, % body wt[c]	.250	.266	.193	.192	.200	.201

[a]Values are means for three pens of pigs with 16.7 lb avg initial wt and allowed to consume feed *ad libitum* with a five-hole feeder in each pen.

[b]Values are means for 16 pigs per treatment.

[c]Values are means for four pigs per treatment and determined on day 29 of the test.

Effect of Neomycin and Carbadox on Growth, Fasting Metabolism, and Gastrointestinal Tract of Young Pigs

Jong-Tseng Yen, John A. Nienaber, and Wilson G. Pond[1]

Introduction

Subtherapeutic levels of antibiotics and other antimicrobial agents have been used for over 30 yr to improve rate of wt gain and feed efficiency in food animals. However, it is still not clear how antimicrobial agents promote animal growth. Reduced wt of the small intestine has been observed in pigs fed chlortetracycline and carbadox, a synthetic, growth-promoting antimicrobial agent. Due to its high metabolic rate, the gastrointestinal tract has been suggested to contribute significantly to total body fasting heat production. Thus, one should expect animals with reduced small intestinal mass to have a lowered fasting heat production and to divert a higher portion of ingested energy and nutrients to body wt gain. Indeed, a trend toward a higher body wt gain with concomitant lower small intestinal wt was observed in our previous study with pigs fed carbadox. However, no consistent reduction in whole-animal fasting heat production of pigs fed carbadox could be demonstrated in that study. One objective of this study was to determine whether giving pigs a longer adaptation period in the calorimeter would improve the precision and reproducibility of our calorimeter because, in our previous studies, pigs were allowed only 6 to 8 hr adaptation to the unfamiliar calorimeter settings before heat production was measured. Another objective was to evaluate the effect of neomycin and carbadox on fasting heat production in pigs because, in rats, neomycin had been shown to reduce oxygen consumption.

Procedure

Five sets of crossbred littermate gilts that had never received any dietary antimicrobial agents and had been group-fed *ad libitum* for 1 wk a 16% crude protein corn-soybean meal basal diet were used. They were randomly assigned within litter to 1) the basal diet, 2) the basal + .308% neomycin, or 3) the basal + 55 ppm carbadox. The pigs were housed individually in cylindrical metabolism cages and fed an equal amount of feed within litter once daily for 16 days. After feeding on day 16, the pigs were moved to the calorimeters. The heat production of the pigs during the 8- to 24-hr after-feeding period was determined.

The pigs were kept continuously in the calorimeters, and each set was equally fed once daily for 5 more days. Heat production was measured during the 8- to 24-hr after-feeding period on days 4, 5, and 6 and during the 32- to 48-hr after-feeding period following day 6 feeding. The pigs were killed 50 hr after the last feeding for gastrointestinal tract and carcass measurements.

Results

The effects of dietary supplementation of neomycin or carbadox on the performance and gastrointestinal tract of pigs are summarized in Table 1. The daily gain and feed efficiency of pigs fed the diet supplemented with neomycin or carbadox were significantly improved compared with those of pigs fed the basal diet. Pigs fed diets supplemented with antimicrobial agents had significantly lower fresh wt of small intestine, whether expressed as absolute wt or as a percentage of slaughter wt.

As shown in Table 2, neither dietary supplementation of neomycin or carbadox, nor the length of adaptation had any effect on fasting heat production of pigs. Compared with the 8- to 24-hr after-feeding period, fasting heat production during the 32- to 48-hr after-feeding period was significantly lower.

The effect of carbadox supplementation on the performance, gastrointestinal tract, and fasting heat production in pigs, as shown in the present study, are in agreement with our previous study. The present study also demonstrated that neomycin has similar effects to those of carbadox on the performance, gastrointestinal tract, and fasting heat production of young pigs. Unlike rats, pigs fed a neomycin-supplemented diet did not have reduced fasting heat production as compared with those fed the basal diet.

The consistent improvement in the rate and efficiency of body wt gain with concomitant lower fresh wt of small intestine in pigs fed carbadox, as observed in the present and previous studies, suggest that the growth-promoting effect of carbadox and neomycin is related to the reduction of small intestinal mass. However, in both our previous and present studies, no consistent reduction of whole-animal fasting heat production was detected. This failure apparently is not caused by the relative insensitivity of our calorimeters due to the possible adaptive adjustments of metabolism of the pigs in calorimeters, because similar heat production values during the 8- to 24-hr after-feeding period were obtained during days 1, 4, 5, and 6 in the calorimeter. It may be caused by the confounding effect of increased heat production from enhanced body protein accretion as a result of feeding antimicrobial agents. Improved retention of dietary protein has been reported in young pigs fed carbadox. Thus, to clearly illustrate the effect of antimicrobial agents on the metabolic rate of the small intestine, oxygen consumption by the small intestine itself, instead of the whole animal, should be determined.

Table 1—Performance and gastrointestinal tract of pigs[a]

Item	Diet		
	Basal	Neomycin	Carbadox
Avg daily gain, lb	.19[b]	.27[c]	.26[c]
Gain/feed	.31[b]	.45[c]	.42[c]
Slaughter wt, lb	21.81	27.51	22.33
Stomach wt, lb	.21	.21	.23
Small intestine			
Fresh wt, lb	.80[b]	.72[c]	.74[c]
Fresh wt/slaughter wt, %	3.69[b]	3.24[c]	3.33[c]
Cecum wt, lb	.04	.04	.05
Colon + rectum wt, lb	.32	.30	.29

[a]Values are means of five pigs weighing 18.06 lb initially and equally fed for 21 days; cumulative avg daily feed intake for the 21 days was .61 lb.

[b,c]Means in the same row with different superscripts differ ($P<0.05$).

[1]Yen is a research animal scientist, Nutrition Unit; Nienaber is an agricultural engineer, Biological Engineering Unit; and Pond is the research leader, Nutrition Unit, MARC.

Table 2—Effect of dietary neomycin or carbadox and of length of adaptation to calorimeter on fasting heat production of pigs

Item	Diet[b]			
	Basal	Neomycin	Carbadox	Avg
8 to 24 hr after feeding[c]				
Day 1 in calorimeter (16 days on test)	5.65	5.34	5.30	5.43
Day 4 in calorimeter (19 days on test)	5.71	5.46	5.41	5.53
Day 5 in calorimeter (20 days on test)	5.80	5.76	5.42	5.66
Day 6 in calorimeter (21 days on test)	5.64	5.39	5.45	5.54
Avg[d]	5.70	5.52	5.40	
32 to 48 hr after feeding[c d]	4.88	4.83	4.50	4.74

[a]Values are expressed as kcal per hr per metabolic body wt.

[b]Each diet was fed to five pigs.

[c]No effect ($P>0.05$) due to dietary supplementation or the length of adaptation to the calorimeter.

[d]Significant effect ($P<0.01$) due to the length of fasting.

Copper Sulfate Reduces Intestinal Urease Activity in Swine

Vincent H. Varel, Isadore M. Robinson, and Wilson G. Pond[1, 2]

Introduction

Production of ammonia via hydrolysis of urea in the rumen and large intestine is thought to be important in the nitrogen metabolism of animals. Large amounts of urea enter the rumen and intestinal tract from the blood stream, saliva, or dietary sources and are hydrolyzed by bacterial enzymes (ureases) to carbon dioxide. High concentrations of ammonia in the intestinal tract can be toxic and, thus, increase turnover of intestinal epithelial cells or the intestinal lining. With the increased turnover, the animal is forced to expend greater energy for maintenance of the intestinal tract, and less energy is available for growth or wt gain. Therefore, with a significant amount of ammonia derived from urea in the intestinal tract, compounds which reduce urease activity or bind ammonia may reduce the amount of ammonia to which intestinal epithelial cells are exposed, reduce epithelial turnover, and thus leave more energy available for body growth. Copper sulfate, used extensively in animal feeds in Europe, is an inhibitor of sulfhydryl enzymes, including urease. Clinoptilolite, a natural zeolite with high ammonia-binding capacity, has been shown to reduce portal blood ammonia in ammonia-intoxicated animals and to improve wt gain and efficiency of feed utilization under some conditions, which are primarily related to purity and the level of supplement fed.

Little information is available describing the bacteria which produce urease in the intestinal contents of the pig. The objectives of this study were to determine the predominant urease producing bacteria in the pig intestinal tract and determine how their numbers and total urease activity are affected when copper sulfate, Aureo SP250 (chlortetracycline, sulfamethazine, and penicillin), or an ammonia-binding zeolite, clinoptilolite, are fed to growing pigs.

Procedure

Four-way cross (Chester White x Landrace x Large White x Yorkshire) growing barrows, approximately 50 lb each, were fed four experimental diets. Groups of four animals each were fed either a basal diet or a basal diet plus copper sulfate, Aureo SP250, or clinoptilolite. All pigs were fed *ad libitum* to a slaughter wt of about 220 lb. Body wt was recorded at the beginning of the experiment and at 4-wk intervals.

Rectal samples of fecal material were collected from all animals after 3, 9, and 14 wk on the experimental diets. All fecal samples were analyzed for total bacteria, urease producing bacteria, urease activity, and ammonia nitrogen.

Results

A comparison of total bacteria and percent urease producing bacteria from fecal samples of pigs fed the four experimental diets is shown in Table 1. Approximately 27% of the total bacteria cultured from pigs fed the basal diet were able to hydrolyze urea. Streptococci bacteria represented 74% of all ureolytic bacteria from the fecal flora of pigs. Overall total bacteria from fecal samples of pigs fed the four experimental diets were not different. However, the overall proportion of total organisms that were ureolytic was different. Fecal samples from pigs fed the basal diet and the basal diet plus clinoptilolite contained approximately 27 and 23% ureolytic bacteria, respectively. Only 10% of the organisms were ureolytic from the fecal samples of pigs fed the diets containing copper sulfate or Aureo SP250. This indicates that copper sulfate or a combination of antibiotics in Aureo SP250 reduced the total number of ureolytic microorganisms from 27 to 10% of the total flora.

Copper sulfate in the diet was the only compound that decreased fecal urease activity (Table 2). Even though Aureo SP250 decreased the number of ureolytic bacteria, fecal urease activity was not reduced. Fecal ammonia concentrations were not different between diets, which may suggest that deamination of amino acids plays a significant role in the amount of ammonia found in the intestinal tract. Plasma urea nitrogen was also not different between treatments.

The fact that only copper sulfate reduced urease activity in the intestinal tract suggests that the antibiotics may reduce selected urea-hydrolyzing organisms, while at the same time the remaining urea-hydrolyzing species increase the synthesis of the enzyme urease to maintain the fecal urease activity at levels comparable to those of controls. Thus, future studies might involve inhibiting other enzyme activities in the intestinal tract to see if a desired response is obtained. This approach may be more effective than inhibiting a selected group of bacteria to produce a desired effect, especially if the particular enzyme activity is distributed among many different bacterial species.

In this study, the desired effect—an increase in daily wt gain—was not attained with the concentration of copper sulfate or clinoptilolite fed. However, in other studies in which the level of copper sulfate was double (250 mg/kg) that used in this study, a significant increase in daily gain was obtained. Clinoptilolite also produced a similar response in daily gains. Purity of the clinoptilolite was felt to be important in obtaining a positive growth response.

While it is still unclear how subtherapeutic levels of antibiotics in animal feeds promote weight gain, antibiotics in feeds have become a controversial issue because of the potential for microorganisms to develop resistance. Thus, research into a non-antibiotic agent such as copper sulfate, which has the potential to inhibit urease activity, and clinoptilolite, which binds cations, while both stimulate a positive growth response in animals, should be pursued further.

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[1]Varel is a research microbiologist, Nutrition Unit, MARC; Robinson is a research microbiologist, National Animal Disease Center, Ames, Iowa; and Pond is the research leader, Nutrition Unit, MARC.

[2]The full report was of this work was published in Appl. Environ. Microbiol. 53:2009-2012, 1987.

Table 1—Comparison of colony counts and percent ureolytic bacteria from fecal samples of pigs fed various experimental diets

Time on diet (wk)	Diet	Total bacteria (x 10^{10} g dry wt)	Urease producing bacteria (%)
3	Basal	21.9	25.2
	Copper sulfate[a]	15.6	13.5
	Aureo SP250[b]	13.8	15.8
	Clinoptilolite[c]	15.0	30.5
9	Basal	13.1	20.8
	Copper sulfate	11.0	4.8
	Aureo SP250	7.8	6.1
	Clinoptilolite	14.7	14.0
14	Basal	8.4	35.6
	Copper sulfate	8.6	11.4
	Aureo SP250	7.8	8.5
	Clinoptilolite	9.3	25.0
Overall	Basal	14.4	27.2
	Copper sulfate	11.7	9.9
	Aureo SP250	9.8	10.1
	Clinoptilolite	13.0	23.2

[a]125 mg per kg feed.

[b]110 mg clortetracycline, 110 mg sulfamethazine, and 55 mg penicillin per kg.

[c]20 g per kg feed.

[d e]Means in columns with different superscripts differ ($P < 0.05$).

Table 2—Comparison of urease activity and ammonia concentrations from fecal samples of pigs fed various experimental diets for 14 wk

Diet	Urease activity (mg of NH_3/min per g dry wt)	Ammonia conc. (mg of NH_3/g dry wt)
Basal	0.48[a]	8.9
Copper sulfate	0.30[b]	8.4
Aureo SP250	0.45[a]	8.0
Clinoptilolite	0.52[a]	8.4

[a b]Means not having a common superscript differ ($P < 0.10$).

Activity of Fiber Degrading Microorganisms in Lean, Obese, and Contemporary Swine Genotypes

Vincent H. Varel, Hans G. Jung, and Wilson G. Pond[1,2]

Introduction

Digestion in the pig large intestine is comparable to rumen fermentation in many aspects; however, it is not well understood. Fiber in the form of cellulose and hemicellulose is one of the major substrates fermented in the large intestine. Various studies suggest that the pig can utilize fiber for growth, and up to 30% of its maintenance energy may be derived from volatile fatty acids produced in the large intestine. This figure may be even higher for adult animals, because sows can maintain normal reproductive performance when fed diets containing 96 to 100% alfalfa meal. The total number of microorganisms in the pig large intestine do not change when a high fiber diet such as 50 or 80% alfalfa meal is fed. However, the fiber-degrading organisms increase and obviously replace others. The increase in fibrolytic bacteria normally coincides with an increase in enzyme activity (cellulase and xylanase), indicating that diet can be used to enhance fibrolytic activity. This is true for growing pigs and adult animals. The cellulolytic organisms in the pig, *Bacteroides succinogenes* and *Ruminococcus flavefaciens*, are similar to those in the rumen and are present in comparable numbers. This explains in part why adult pigs can maintain themselves by merely grazing on forage in pastures. Assuming other conditions are met, there is a significant potential for fiber degradation in the pig large intestine.

Whether various genotypes, such as the genetically selected obese and lean pigs, have different abilities to degrade fiber is unknown. A preliminary study suggested that genetic differences may exist between growing-finishing lean and obese pigs in their cellulolytic microflora, and thus in their ability to adapt to high fiber diets. The obese and lean genotype pigs have been selected over 14 generations for backfat thickness and have been used as models for various studies. The gastrointestinal tracts of lean pigs are heavier than those of obese pigs when a high fiber diet is fed. However, a study examining the digestibility of fiber in obese pigs has not been conducted.

The objectives of the present study were to determine the effects of including 80% alfalfa meal (high fiber) in a diet fed to young adult pigs of three genetic backgrounds. Digestibility of the diet constituents, rate of passage of feed residues through the gastrointestinal tract, and number of cellulolytic microorganisms in the tract are reported.

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[2]A full report on this work can be found in J. Anim. Sci. 66:707-712, 1988.

Procedure

Twenty-one genetically lean, obese, and contemporary crossbred young adult (6 mo old) castrated male pigs were fed either an 80% alfalfa meal diet (high fiber) or a control diet (low fiber) for 71 days. Four pigs from each genotype were fed the high-fiber diet, and three of each genotype were fed the control diet. Rectal samples of fecal material were collected at days 0, 14, 35, and 49 from the four pigs in each group fed the high-fiber diet and from all pigs 24 hr before slaughter (day 71). Samples were analyzed for number of cellulolytic bacteria and *in vitro* digestibility of alfalfa meal fractions. On day 56 of the experimental diets, a pulse dose of chromium-mordant cell walls from alfalfa was mixed with the daily rations for all pigs fed the high-fiber diet to examine digesta rate of passage. Acid insoluble ash content of fecal samples was used to calculate *in vivo* digestibility of the diets.

Results

In vivo digestibility of dry matter, crude protein, cell walls, hemicellulose, cellulose, and gross energy across both the low-fiber and high-fiber diets was less for the obese pigs than for the lean or contemporary genotypes (Table 1). As expected, digestibility of the high-fiber diet was less than digestibility of the low-fiber diet for all three genotypes.

Table 2 shows data on cellulolytic bacteria and *in vitro* digestibility of alfalfa fiber fractions in relation to sampling time for pigs fed the high-fiber diet. The number of cellulolytic bacteria were greater in the control animals (day 0) after the high-fiber diet was fed. This corresponded to an increase in digestibility of the alfalfa meal fiber fractions. Age of the pigs, young adulthood, did not affect *in vitro* digestibility. Bacterial populations appeared to adapt to the high-fiber diet within 14 days, and no changes in digestibility of fiber were seen after this initial 14-day period. Previously, we observed a 6.7-fold larger population of cellulolytic bacteria in the lower intestinal tract of the adult pig fed a high fiber diet than in the growing pig.

Data on rate of passage of feedstuffs through the gastrointestinal tract is given in Table 3. The estimates of intestinal compartment turnover (λ, see Table 3), did not differ among the swine genotypes. The obese swine did have a shorter residence time due to displacement flow (Υ) than the other two genotypes. This effect of Υ was also responsible for a shorter mean residence time (MRT) or faster rate of digesta passage, for the obese genotype. Other studies have shown that the volume of the colon of obese pigs was less than that of the other genotypes. It appears that digesta movement through the gut is very similar among the genotypes, as shown by the equal compartmental turnover values; but, because of

Table 1—*In vivo* digestibility of high-fiber and low-fiber diets by three pig genotypes

	Digestibility, %											
	Dry matter[a b]		Crude protein[a b]		Cell walls[a b]		Hemi-cellulose[a b]		Cellulose[a b]		Gross energy[a b]	
Genotype[c]	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Obese	45.9	84.5	53.1	76.4	17.0	62.3	34.1	65.1	14.0	64.0	41.9	84.7
Lean	53.4	88.2	59.5	82.8	29.4	80.8	43.8	83.9	29.5	78.2	51.7	88.5
Contemporary	50.8	87.1	58.3	80.8	24.4	78.5	39.2	82.6	23.1	71.0	47.7	87.1

[a]80% alfalfa meal diet (high); corn-soy diet (low).

[b]Digestibility of the corn-soy diet was greater ($P<.05$) than that of the 80% alfalfa meal diet for all genotypes.

[c]The obese pigs had a lower ($P<.05$) digestibility of all diet components for both diets than the lean or contemporary genotypes.

Table 2—Comparison of cellulolytic bacteria counts and 48 hr *in vitro* digestibility of alfalfa fiber fractions inoculated with fecal samples from three pig genotypes fed 80% alfalfa meal

Time on diet, days	Cellulolytic bacteria[b] 10^8g dry wt	Digestibility of alfalfa meal (g/g fecal dry matter added[a])		
		Cellulose	Hemicellulose	Cell walls
0	8.0	.35	.40	.81
14	14.5	1.51	1.55	3.12
35	31.1	1.80	1.74	3.64
49	24.7	1.70	1.83	3.52
70	37.3	1.62	1.70	3.37

[a]Significant ($P<.05$) effect of time.

[b]Significant ($P<.05$) effect of time.

Table 3—Digesta passage measurements for three pig genotypes fed 80% alfalfa meal

Genotype	Passage measures[a]		
	λ	Υ	MRT, h
Obese	.119	14.6[b]	32.4[b]
Lean	.105	25.1[c]	44.7[c]
Contemporary	.100	22.9[c]	43.1[c]

[a] λ, age-dependent rate parameter for compartmental turnover: Υ, residence time due to displacement flow; MRT, mean residence time.

[b c]Means in the same column with different superscripts differ ($P<.05$).

the larger size of the gastrointestinal tract of lean and contemporary swine, the residence time is increased relative to obese swine fed at the same level of intake.

All three swine genotypes were fed equivalent rations; thus, with the observed smaller colon digesta content of obese pigs found previously, either *in vivo* digestibility must be greater or rate of passage must be faster. Across both diets, obese swine had lower *in vivo* digestibility coefficients than lean or contemporary swine (Table 1). The *in vitro* data (not shown) do not support the proposal of a higher digestibility of fiber by obese pigs. The faster rate of passage would explain the lower *in vivo* digestibility and smaller amount of digesta found in the obese pigs.

The statement is often heard that Chinese pigs are able to thrive on high fiber diets, but published data to support this concept are lacking. However, within the next 2 yr, we may be able to test this possibility on imported Chinese pigs at MARC.

Prolactin is a Participant in the Stress Response of Pigs

Harold G. Klemcke[1, 2]

Introduction

Prolactin (PRL) is a pituitary-derived hormone (a blood-borne chemical messenger) which has a primary function in most mammalian species to stimulate development of the mammary gland and its milk synthesis and secretion. However, many additional functions of PRL have been demonstrated, one of which is modulation of adrenal gland function. This endocrine gland is extremely responsive to adverse environmental conditions—stressors—via secretion of steroid hormones such as cortisol. Traditionally, it is believed that these steroids assist in the adaptation to the stressor, at least initially.

Not only are adrenal steroids secreted in response to stressors, but also a variety of animal species respond to various acute stressors—restraint, handling, heat, ether exposure—by an increase in plasma PRL. Swine, however, would be unique if plasma PRL levels were unaffected by short-term stressors.

Hormonal receptors are molecular structures located on the surface of, or within, cells. These structures are vitally important in terms of a hormone's ability to communicate with hormone-responsive tissues because they provide the means by which hormones initially interact with cells. Receptors serve two fundamental roles: recognition of specific hormones and transfer of the hormonal message to the cell.

It would seem likely, therefore, that if PRL is involved in the stress response of pigs, then one should be able to measure changes in plasma concentrations when pigs are subjected to stressors. Further, if PRL is to modulate adrenal function—a primary participant in the stress response—under basal or stressor-altered conditions, then, of necessity, there must be PRL receptors present on cells of the adrenal gland. The studies detailed below were conducted to test for these possibilities.

Procedure

Twenty crossbred barrows (¼ Yorkshire: ¼ Landrace: ¼ Large White: ¼ Chester White) weighing 154-224 lb were used in an acute stressor study. Barrows were housed in environmental chambers measuring 16 x 17 ft, capable of maintaining a temperature range of -4 to 104°F. Within these chambers, each barrow was housed in an individual pen of dimensions 2 x 4 ft. Each animal had visual, olfactory, auditory, and tactile contact with another animal in an adjacent pen. Animals were provided a corn and soybean meal-based ration and water *ad lib*. Throughout both studies, animals were maintained in a photoperiod consisting of 12 hr light (lights on 6:00 a.m.-6:00 p.m.)

A catheter was surgically implanted in the jugular vein of Halothane-anesthetized pigs 6 to 7 days prior to treatment initiation. Prior to blood sampling, a 5 to 6 ft catheter extension was attached to each animal to allow blood to be obtained from outside the pen and without disturbing the pig. This experiment included the following four treatments to which pigs were randomly assigned: (1) 5 control animals sampled during the morning and afternoon hours (7:00 a.m.-4:00 p.m.); (2) 5 pigs subjected to a 20-min restraint (8:00-8:20 a.m.); (3) 5 pigs subjected to 90°F for approximately a 2-hr period (8:00-10:00 a.m.); and (4) 5 pigs subjected to a 20-min restraint (8:00-8:20 a.m.) and to 90°F for 2 hr (8:00-10:00 a.m.). Blood samples were obtained at 20-min intervals initially (7:00-11:00 a.m.) and at hourly intervals thereafter (12:00-4:00 p.m.).

Pigs subjected to restraint were transferred from their pens to a mobile restraining cage constructed of steel bars padded with foam rubber with cage dimensions of 4 ft long x 0.8 ft wide x 2.3 ft high. One side of this cage was adjustable; hence, the pig could be firmly immobilized without causing it physical pain. Transfer time was 2 to 4 min, and blood samples were taken immediately after transfer (8:00 a.m.). A subsequent blood sample was obtained just prior to returning the pig to its home pen (8:20 a.m.). Pigs subjected to 90°F were transferred from their home pen to a similar pen in a second environmental chamber 24 hr prior to treatment. At 8:00 a.m. on the day of treatment, the temperature in the environmental chamber was increased from 68 to 90°F. Two hours after the initial temperature change, ambient temperature was returned to 68°F. In this study, pigs were maintained at 68°F and an average relative humidity of 33%, except for those animals subjected to a transient 90°F and a relative humidity of 20%. (Treatment groups 3 and 4).

In separate studies, PRL receptors were measured in either a cell-free tissue preparation of the adrenal cortex or in isolated adrenal cells. The receptor assay involved use of radioactive ovine PRL.

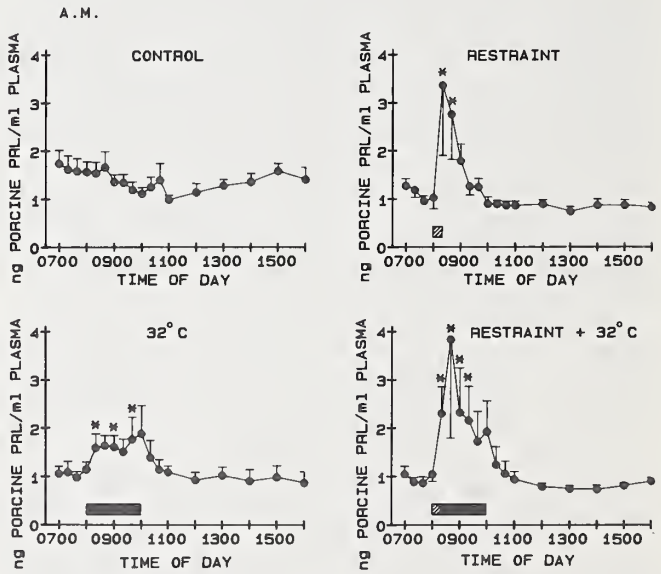

Figure 1—Plasma porcine PRL concentrations in control or morning stressor-treated barrows. Control and restraint animals were maintained at 68°F throughout the study. One group of five barrows was placed in a restraining cage for a 20-min period (8:00-8:20 a.m.), as indicated by the hatched bar. A second group of five barrows was subjected to 32°C (equal to 90°F) for 2 hr (8:00-10:00 a.m.), as indicated by the solid bar. A third group of five barrows was concomitantly subjected to restraint (8:00-8:20 a.m.) and to 32°C (equal to 90°F) from 8:00-10:00 a.m. Blood samples were obtained via jugular catheter and at 20 min (7:00-11:00 a.m.) or hourly (12:00-4:00 p.m.) intervals. Each datum point represents the average of five observations. The bars represent a measure of the error or variability—standard error of the mean—associated with each datum point. Averages significantly greater than pretreatment basal levels are designated with an *.

[1]Klemcke is a research physiologist, Biological Engineering Unit, MARC.

[2]The expert technical assistance of David Sypherd and Moira Wilhelm is gratefully acknowledged.

Results

Acute stressor study. For controls, there were no significant differences among hours in plasma PRL concentrations (Fig. 1). Rather, the levels remained relatively constant at an overall average of 1.34 nanograms/milliliter (ng/ml). Restraint for 20 min and the associated activities of moving the pigs into the restraining cage induced within 20 min very dramatic increases in plasma PRL (Fig 1). Such increases were transient, and plasma PRL levels returned to levels not significantly different from pre-stressor baseline levels within 40 min after removing animals from the restraining cage. There was considerable variability in the magnitude of individual responses to restraint which could not be readily correlated with behavioral response to restraint, that is, the duration or magnitude of struggling, panting, or vocalizations.

Subjecting pigs to an ambient temperature of 90°F for 2 hr produced a more moderate, but still significant, increase in plasma PRL which rapidly returned to baseline levels after treatment termination. Combined application of both stressors initiated the dramatic increase in PRL previously observed with restraint. Additionally, there tended to be a prolongation of the elevated PRL response when both restraint and 90°F stressors were applied (Fig. 1).

PRL receptors were readily demonstrable in the porcine adrenal cortex (Fig. 2). Of the tissues examined, the adrenal cortex and kidney had the highest concentrations, and heart, lung, skeletal muscle, spleen, and thymus had almost unmeasurable levels. The adrenal medulla also appeared to have very high concentrations of PRL receptors. However, subsequent tests using purified cells from medullary dissections indicated that sufficient amounts of contaminating adrenocortical cells were present to account for at least part of this binding.

Additional studies using isolated adrenal cortical cells were conducted. In these studies, a constant number of cells from three pigs was incubated with increasing amounts of radioactive ovine PRL. The amount of radioactivity bound to the cells was then measured, and the data were plotted as indicated in Figure 3. Although the plots are slightly different among the three pigs, the straight lines in each case indicate that there is a single type of PRL receptor on the cells. The slope of the lines provides a measure of the strength of attraction between the hormone and its receptor; that is to say, the affinity as measured by the equilibrium association constant (Ka). In this case, there are large Ka values indicative of a high affinity. Finally, the intersect of the plot with the X-axis can be used to determine the number of receptors present on a cell. In this case, there were, on the average, about 6,500 receptors per cell. Additional results (which are not shown) indicated other characteristics of these receptors, such as their ability to bind specifically with the PRL molecule.

Such data indicate—for the first time—that plasma PRL is increased in pigs in response to at least two different stressors. Additionally, the presence of specific, high affinity PRL receptors on cells of the adrenal cortex has been demonstrated. This indicates that PRL is a participant in the porcine stress response, and suggests that one site of action may be the adrenal gland. The exact role of PRL in modulation of porcine adrenal function remains to be determined.

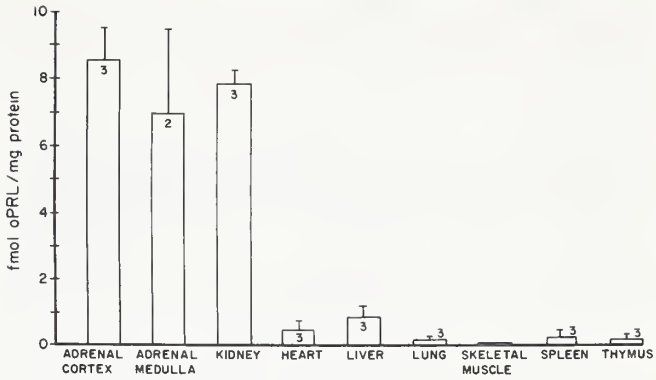

Figure 2—Binding of ^{125}I-oPRL to various tissues of castrated male pigs. The number in or near the bar indicates the number of pigs from which the tissues were obtained.

Cell Preparation	Ka ($10^{10}M^{-1}$)	Maximal Binding pM/100,000 cells	Maximal Binding Binding sites/cell
A	2.30	2.29	6904
B	4.71	1.87	5618
C	3.11	2.25	6789
Mean	3.37	2.14	6437

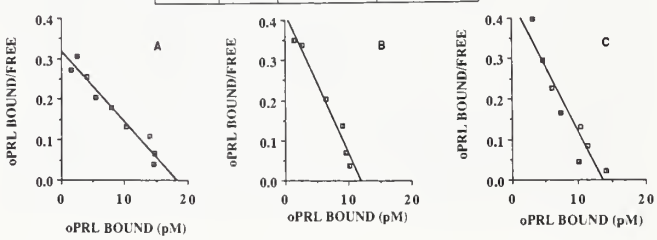

Figure 3—Scatchard plots and final Scatchard analyses of binding of ^{125}I-oPRL to isolated porcine adrenocortical cells from 3 barrows.

Energetics of Activity

Timothy P. McDonald and John A. Nienaber[1]

Introduction

Activity accounts for up to 20% of the total energy expenditure of the growing pig. From a research standpoint, activity represents an important factor in an animal's overall energy balance. Modeling the growth of swine, measuring their maintenance energy requirement, or designing housing facilities all require some knowledge of how activity affects available energy pools. Despite this, estimates of the increase in energy use during activity for swine have been scarce and, when reported, highly variable. This is mainly due to the difficulties involved in making dynamic measurements of energy consumption, as indicated by heat production, on large, generally uncooperative animals.

Heat production is measured using an indirect calorimeter, a device which detects differences in respiratory gas concentrations between an enclosed chamber surrounding the animal and the outside environment. The enclosing chamber allows detectable changes in gas concentrations to accumulate, but, at the same time, alters dynamic fluctuations in concentration. The overall effect is that the measured dynamic heat production response, as indicated by changes in gas concentration, is both reduced in magnitude and spread out over a relatively long period of time. Previous work at MARC has shown that, although our calorimetry system affects the dynamics of what we are measuring, it does so in a predictable fashion. We were able to develop a mathematical model of the system response which would remove the distortion in dynamic measurements caused by the calorimeter chamber. The objectives of our research were to verify this model and then apply it in establishing the expected increase in heat production associated with various activities in growing-finishing swine.

Procedure

The calorimeter model was verified by comparing its predicted response for a given input with an actual measured response. Ambient air was drawn through the calorimeter and the concentration of carbon dioxide (CO_2) allowed to stabilize. A step change in inlet CO_2 concentration, similar to that produced by an animal during activity, was simulated by introducing a stream of pure CO_2 into the chamber. Outlet concentration of CO_2 was measured for a period of two hours. Model predicted response was then compared to the actual measured output using time series methods.

Results of the model verification experiments showed very good agreement between the predicted and measured response of the calorimeter to a step change in inlet CO_2 concentration. Based on these results for a step change in gas concentration, we concluded that the model was adequate in representing the overall dynamic behavior of the calorimetry system. It was then possible to apply the model in removing the effects imposed by the calorimeter on measured heat production of swine.

Activity-related increases in heat production were measured using seven crossbred swine (Large White x Landrace x Chester White x Yorkshire). The pigs were penned individually and held at a constant 77°F ambient temperature. They were limit fed a 16% crude protein ration so they were all growing at approximately the same rate of 1.4 lb per day.

Heat production data were collected during three 1-wk trials, with calorimetry performed on one pig each day. A 4-wk interval separated the trials, with avg animal wt of 87, 125, and 164 lb. The pigs were fasted for 24 hr prior to placement in the calorimeter. The pig was placed in the calorimeter at 2 p.m. and data were collected for a 16-hr period. Activity while in the calorimeter was monitored using an infrared emitter-detector placed across the chamber. When the pig stood or sat up, the data collection system began recording oxygen, carbon dioxide, and flow rate data at 13-sec intervals for a 2-hr period. Activity was also recorded on videotape. After converting the gas concentration data to heat production, it was treated using the calorimeter model to recover the original dynamic response of the animal. Increases in heat production were measured relative to that observed while resting just before activity commenced.

Results

Figure 1 shows a typical heat production response for a 120 lb pig both as initially measured and after removing the effects imposed on the response by the calorimeter. Along the top of the Figure is a graphical representation of the observed behavior of the animal during the same time period. The measured response is an illustration of the effect the calorimeter enclosure has on dynamic heat production response. We know from work done with humans that heat production should increase rapidly with the onset of activity, and, unless the animal is exerting itself, should return to normal very soon after activity ceases. Contrary to this, the activity of the animal apparently causes only gradual changes in the measured heat production seen in Figure 1. Also, heat production is elevated much longer than activity itself lasts. After applying the inversion model to remove the calorimeter effects, the response is much closer to what we would intuitively expect. There is a rapid rise in heat production with the onset of activity and a rapid decrease with its cessation. There is a close correlation between the observed behavior and its associated heat production effects, allowing the association of a specific increase in heat production with a specific activity.

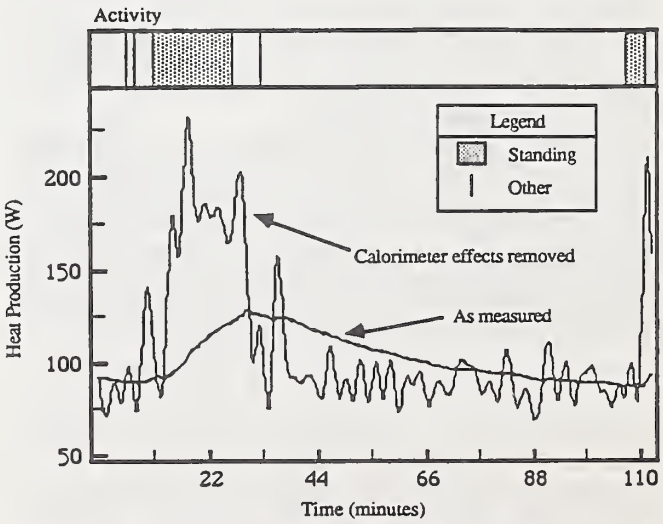

Figure 1—Heat production response of 120 lb pig during activity, as measured, and after treating to remove calorimeter effects.

[1]McDonald and Nienaber are agricultural engineers, Biological Engineering Unit, MARC.

Results of applying the inversion method to the heat production data collected for this experiment are summarized in Table 1. The pigs showed little variation in behavior while in the calorimeter. Their activity was limited mainly to standing and slow movement about the interior of the chamber, with occasional sitting events. Because of this, only three categories of activity were used in the analysis, i.e., long (>4 min) and short (<4 min) duration standing, and sitting. Although there was variation in heat production during activity, the expected rise in heat production associated with activity remained relatively constant.

Table 1—Expected increase in heat production as a result of activity (%)

	Activity		
Weight	Standing (< 4 min)	Standing (> 4 min)	Sitting
87	95.3	119.0	52.8
125	78.6	103.7	72.8
164	90.5	109.5	63.4

Our experiments have shown that it is possible to accurately measure dynamically varying heat production responses in swine. We have demonstrated that specific physical activities can be expected to cause predictable increases in energy use, and that these increases as a percentage of the resting metabolic rate are generally stable. This information is important in understanding the partitioning of available energy by swine under different environmental or management conditions.

Air Temperature Selection Guides for Growing-Finishing Swine Based on Performance and Carcass Composition

G. LeRoy Hahn and John A. Nienaber[1, 2, 3]

Introduction

Swine performance measures (growth, carcass composition, and feed efficiency) are economically important aspects of pig production which are responsive to fixed genetic and dynamic environmental factors. General environmental guides for growing-finishing (G-F) animals have unduly emphasized a narrow band of air temperatures for optimal performance. Selection of thermal environments can be improved through definition of optimal and non-optimal conditions by evaluation of trade-offs associated with sub-optimal conditions. This report provides current information on evaluations for G-F animals based on studies in our MARC controlled-environment laboratory, as well as results obtained at other locations.

Background. Early models of performance were based on short-term measures under thermal stressors and indicated precise optimal temperatures for growth and efficient utilization of feed. In the longer term, however, the animal's adaptive capabilities blur any sharp changes seen in the short term. Relatively "normal" performance is achieved by animals over a broad range of physical, chemical, biological, and social conditions. Only when conditions exceed threshold limits does the animal's performance or health become adversely affected and require attention. Adaptive capabilities of animals must be considered in evaluating stress responses of livestock and their ultimate welfare. Stress, most often considered a negative factor, can also be a positive influence when it leads to coping and adaptation.

Behavioral, physiological, and immunological coping actions of the animal, can be represented schematically (Fig. 1). Such coping actions can lead to longer-term performance responses, characterized in Figure 2. The resulting rate of decline in performance in the nominal loss temperature zone is small.

Response relationships. Data we have published (see footnote 2) support the concepts illustrated in Figures 1 and 2. Figure 3 shows energy intake and usage by *ad lib*-fed G-F swine, based on results of a Kansas State University study. Upper- and lower-limit thresholds based on each of these energetic relationships indicate a broad zone of acceptable air temperatures. Response to air temperature for feed intake, growth rate, and feed conversion (Fig. 4), developed from combined results of studies at MARC and Kansas State University, provide further evidence that broad zones of temperature are acceptable for *ad lib*-fed G-F swine. The relationships serve as the basis for improved environmental design and management guides.

It should be kept in mind that these relationships can be altered by other factors. Shifts in the response relationships can result from feeding management (*ad lib vs* restricted or meal-fed), from biological or social factors (genetics, health, prior conditioning, parasites, group size, activity levels, etc),

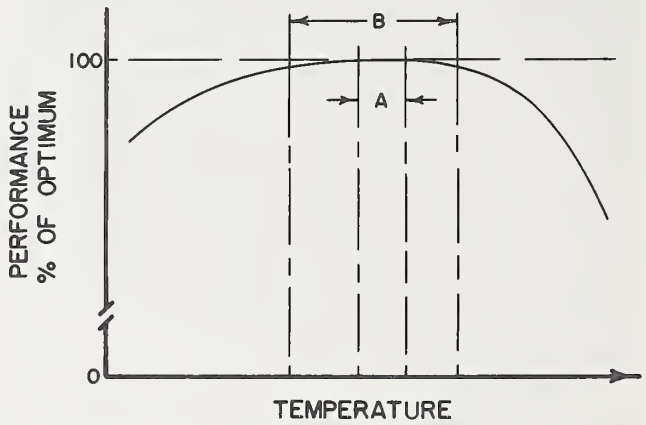

Figure 2—Typical performance response as a function of temperature. Although an optimum temperature may exist for an individual animal at a given time and under specific management practices, optimal conditions for a group of animals involve a slightly wider zone of temperature (A). In addition, performance curves usually show only slight decreases (typically 1 to 3%) from optimum over a somewhat broader range of temperatures ("nominal loss" zone, B).

[1]Hahn and Nienaber are agricultural engineers, Biological Engineering Unit, MARC.

[2]Published reports on which this article is based are Trans. of the ASAE 30(6):1772-1775, 1776-1779 (1987); Applied Engineering in Agriculture 3(2):295-302 (1987); and Proc., Third Intl. Livestock Environment Symposium (Amer. Soc. Agric. Engrs):93-100 (1988).

[3]The authors would like to acknowledge J. T. Yen, research animal scientist; Eldon Shetler, research technician; Lynn Gose, engineering technician; and Neal Kreutz, agricultural research technician, for their input and assistance in conducting the controlled-environment temperature study; and Gary Wieman, statistical coordinator, for his assistance in development of response relationships.

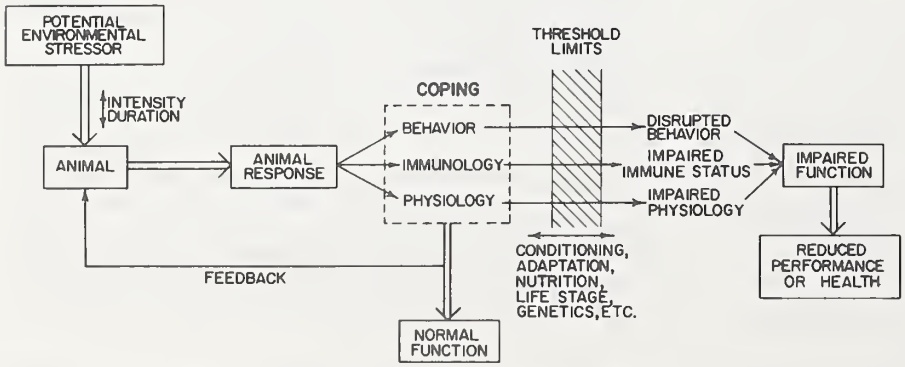

Figure 1—Responses of animals to potential environmental stressors which can influence performance and health.

and from thermal factors other than air temperature which affect heat loss or gain (e.g., humidity, cold or hot surroundings, wet skin, air currents).

Swine behavior is also influenced by the thermal environment, which can shift response relationships. Pigs move to preferred microenvironments when alternatives are available. Other coping behaviors correlated with temperature include: postural adjustments, huddling during cold, and increased water consumption and wetting of skin surfaces during hot periods. However, behavioral categories of resting, moving, and social encounters follow a rhythm unassociated with air temperature. Moreover, feeding behavior may become altered, as illustrated in Figure 5 for *ad lib*-fed pigs in constant or cyclic hot environments. Under cyclic conditions, animals ate more during the coolest portion and less during the hottest portion of the day. While this response may have been a result of the animals' thermoregulatory mechanisms, it caused a higher level of metabolic heat production during the hottest portion of the day. These and other reports suggest that swine do not always respond behaviorally in the most appropriate manner to counter the effects of adverse environments. Therefore, response relationships between specific behaviors and temperature can only be considered indicative, rather than quantitative.

Selection criteria for air temperature. The relationships in Figure 4, together with the MARC data for energy retained in the carcass, were used to determine "optimum" air temperatures and the zones of avg air temperature associated with performance penalties of 1, 2, or 5% (Fig. 6). "Optimum" air temperatures for the best growth rate, feed conversion, and retained energy were calculated to be 60.4°, 67.5°, and 50.5°F, respectively. Growth rate was reduced by 1% or less over the range of 56.5° to 64.4°F. A zone of 63.9° to 71.1°F resulted in a 1% or less effect on feed conversion. Since both criteria are important for growing-finishing facilities, the overlapping portion of the two temperature zones (i.e., 63.9° to 64.4°F) is a logical selection for the 1% or less decline criterion. Establishment of zones based on 2 or 3% declines in growth rate and feed conversion might be more realistic, and result in zones from 62.4° to 66.0°F or 61.3° to 67.1°F, respectively. A 5% nominal loss zone for the same combined performance factors extends from 59.0° to 68.9°F, respectively. Within the nominal performance loss ranges presented, the avg temperature can be attained by permitting daily cycles of up to + 5 to 8 °C without adverse consequences on healthy animals, in the absence of other negative environmental factors such as strong radiative or conductive heat gains or losses from surroundings.

Retained energy in the carcass is also energetically most efficient for the overlapping temperature zones suggested for acceptable growth and feed conversion. However, higher energy retention is associated with a higher percentage of body fat.

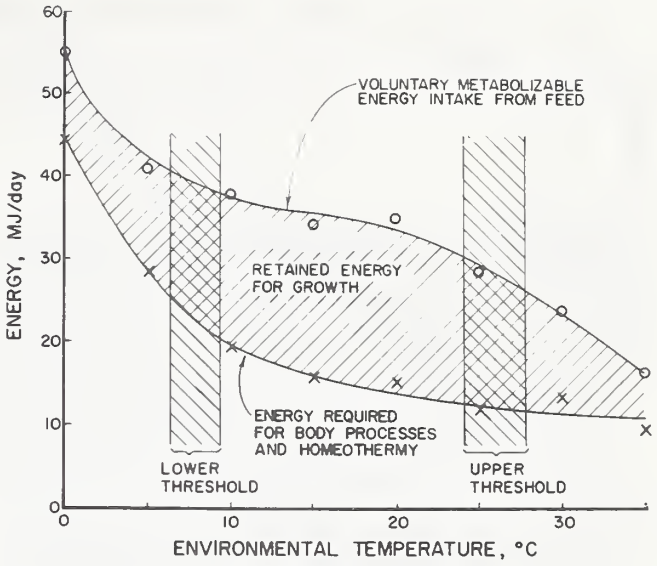

Figure 3—Energetic relationships with environmental temperatures between 32°F (0°C) and 95°F (35°C) based on actual measures during growth of *ad lib*-fed swine from 155 to 220 lb. Threshold limits, which can vary as a result of many factors (e.g., genetics, adaptation), mark the boundaries of nominal performance losses for the animals in this study.

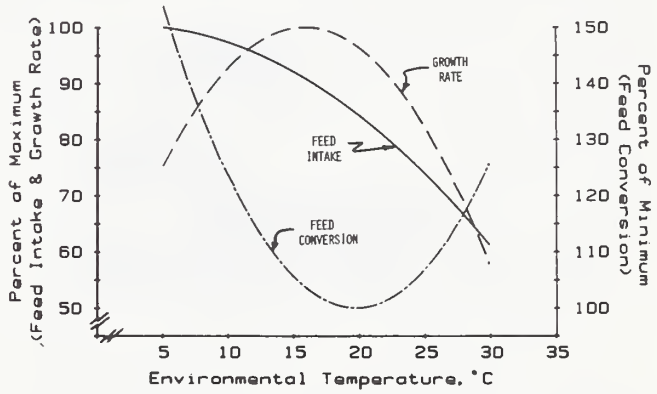

Figure 4—Relative feed intake, growth rate, and feed conversion for *ad lib*-fed growing-finishing swine maintained 4 wk or longer in temperatures between 41°F (5°C) and 86°F (30°C).

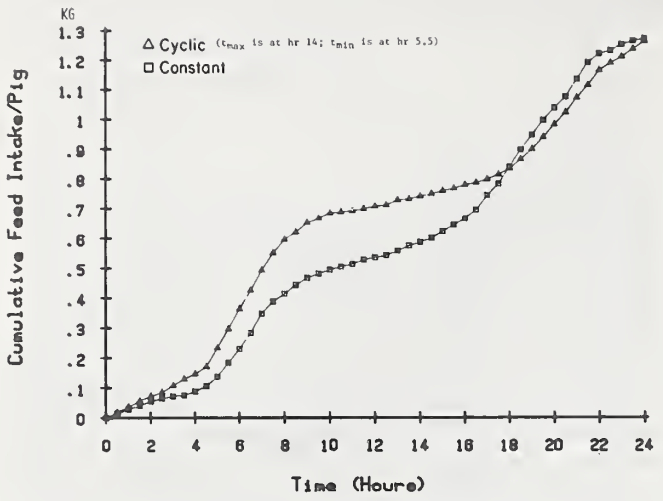

Figure 5—Daily feed intake patterns for *ad lib*-fed growing pigs maintained at 91.4°F constant or 91.4° ± 12.6°F cyclic temperatures. (Time 0 is midnight; 1 kg = 2.2 lb).

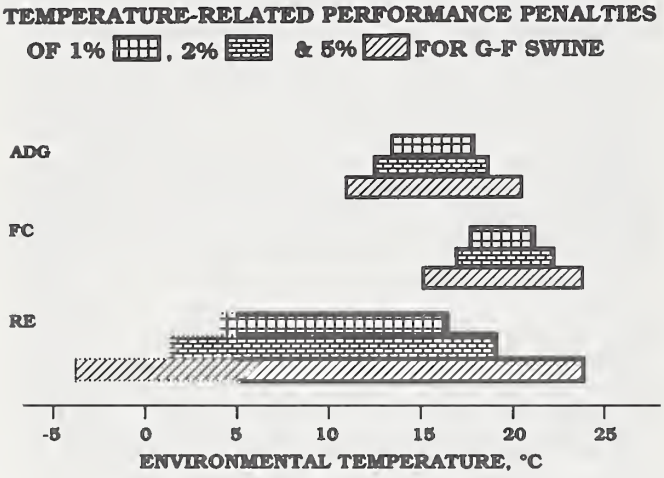

Figure 6—Temperature-related performance penalties for growing-finishing swine in the temperature range from 23°F (-5°C) to 77°F (25°C), where ADG = average daily gain, FC = feed conversion, and RE = retained energy in the carcass. Dashed lines below 41°F (5°C) indicate penalties were obtained by extrapolation below the actual experimental conditions.

Summary

Management of thermal environments in growing-finishing swine facilities can reduce performance-related losses during potentially stressing weather. Maintaining average air temperatures in the range from 54.9° to 66.0°F will provide growth rates for healthy animals within an estimated 2% of the biological optimum, while temperatures of 62.4° to 72.5°F should keep feed conversion within 2% of the optimum. Combining these two parameters provides an average temperature range from 62.4° to 66.0°F as a target for design and operation of the housing facility, based on a nominal loss criterion of 2% or less. Temperature control ranges broader than current recommendations can be appropriate, depending on cost:benefit ratios for economically modifying the environment. Such ratios must be established using costs and returns for individual situations before rational decisions on facility design can be made.

Handling and Transport Effects on Market Hogs—Evaluation of Weight Losses, Physiological Changes, and Meat Quality

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Introduction

Slaughter weight hogs moving from production facilities to slaughter plants are often subjected to periods of fasting with no feed or water available, or limited fasting where water is available. These periods may occur at country buying stations, livestock markets, or at the slaughter plant. In addition, feed and water are not generally available during transport. Fasting or limited fasting may range from 2 or 3 hr up to 72 hr for hogs marketed on Friday and held over to Monday for slaughtering.

The effects of current transportation practices, singly or in combination with fasting, on liveweight loss (shrink), loss of carcass weight, altered meat quality, and physiological changes of slaughter hogs have recently been evaluated in experiments conducted by ARS scientists at MARC and Columbia, Missouri, in cooperation with University of Missouri scientists.

Procedure

Fifty-five slaughter hogs (4-way white crossbreds) raised in MARC production facilities were used in an experiment conducted in June 1986. Forty-nine animals were randomly assigned to the seven treatments (seven hd/treatment) listed in Table 1. The remaining six hogs were randomly assigned to a secondary study of fasting effects of 24, 48, or 72 hr duration on heat production and related measures. These studies were conducted in an indirect calorimeter.

Animals in the control group were individually weighed and loaded onto a trailer, then taken directly from the MARC production facilities to the abattoir (approximately 0.5 mi) for immediate slaughter. Animals in all other groups were similarly weighed on calibrated scales at that time, which was the start of the fasting period. Non-transported animals were fasted (no feed or water) in MARC production facility holding pens for 24, 48, or 72 hr, then slaughtered in the MARC abattoir. The remaining three groups were transported 435 miles to comparable holding pens, including floor area allocations and thermal conditions, at the University of Missouri, Columbia (UMC), where the fasting period was completed. Slaughter of transported animals was in the UMC abattoir on the same date and time as comparable animals fasted at MARC.

Transportation of the hogs from MARC to UMC was in a 6.5 x 16 ft livestock trailer, with approximately 5 ft^2 of floor space per hog (slightly more than recommended guidelines of the Livestock Conservation Institute). The trailer was bedded with wood chips and wetted sand with the bedding re-wetted once about 4 hr into the transit period. Transit time was approximately 9 ½ hr with the hogs being on the trailer approximately 11 hr. The weather was quite similar at both locations during the holding period, with resulting temperature maxima in the holding facilities near 86°F each day and minima near 70°F; avg temperature was approximately 79°F.

All of the hogs were weighed individually at the end of the 24, 48, or 72 hr fasts as they entered the abattoir. At slaughter, weights were recorded for blood, feet and dew claws, head, heart, liver, spleen, gall bladder, kidneys, lungs and trachea, gastrointestinal (GI) tract (full and empty), and carcass so that an accounting could be made of the liveweight for each animal. The stomach, small intestines, cecum, and large intestines were weighed full and empty to determine the amount of contents in the GI tract. The contents were also sampled and analyzed for dry matter. Calibration checks were made on all scales used for liveweights and body components.

Blood samples were taken before treatments were imposed and again immediately prior to slaughter. Hematocrit values and white blood cell counts were determined and the blood samples were then processed for further analyses.

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[2]The assistance of the following persons in conducting the study is gratefully acknowledged—Jenell Dague, Miriam Eckblade, Deb Glenn, Lynn Gose, Linda Hickam, Kurt Holiman, Harold Huff, Neal Kreutz, Paul Little, Scott McClure, Kathy Mihm, Angie Seamans, Eldon Shetler, David Sypherd, Ted Acton, and Dr. H. G. Klemcke.

[3]Liveweight and carcass weight losses were published in Applied Engineering in Agric 4(3):254-258, 1988, and physiological and meat product aspects were published in J. Anim. Sci. 67:334-341, 1989.

Table 1—Slaughter wt, shrink, GI tract contents, and losses in the GI tract contents resulting from fasting or fasting plus transport*

Treatment	Adjusted slaughter wt, lb	Shrink		Difference from controls, lb	GI tract contents, lb	GI tract contents loss, lb	GI tract contents loss as % of total livewt loss
		Initial wt basis					
		lb	%				
Control	210.7	.5	.2		10.0		
24 hr Fast	204.4	6.8	3.2	6.3	6.1	3.9	61.9%
+ Transport	201.5	9.7	4.6	9.2	5.4	4.6	50.0%
48 hr Fast	198.6	12.6	6.0	12.1	4.8	5.2	43.0%
+ Transport	196.2	15.0	7.1	14.5	3.6	6.4	44.1%
72 hr Fast	195.0	16.2	7.7	15.7	3.5	6.5	41.4%
+ Transport	190.9	20.3	9.6	19.8	2.8	7.2	36.4%

*Transport of 435 miles at start of fast period.

Carcass data were collected on length, muscling score, backfat thickness and longissimus muscle area, color, and marbling score. All soft tissue from the right ham of each carcass was ground and analyzed for fat, protein, and moisture. A 6-in loin section was removed rearward of the 10th rib of each carcass for shearing force measures and taste panel evaluation of juiciness, tenderness, and desirability.

Results and discussion

Table 1 presents liveweights at slaughter (adjusted on the basis of a common initial wt of 211.2 lb), shrink comparisons based on initial wt and as a difference from the controls, and GI tract content wt and losses computed relative to the controls for each treatment. Carcass wt (including losses relative to the controls) and yields and liver wt data are provided in Table 2.

Liveweight shrink between the production facility and the abattoir ranged from 6.8 to 16.2 lb for the fasted only treatments, and from 9.7 to 20.3 lb for the fast plus transport treatments. Liveweight and subsequent carcass wt losses are plotted as a function of time in Figure 1.

Carcass yields declined as the length of fast increased, when calculated as a percentage of the adjusted avg wt measured at the production facility at the beginning of the experiment. However, percent carcass yields increased with longer fasting periods when liveweight at slaughter was used as the basis of calculation.

Liveweight shrink and carcass losses quite similar to comparable animals in the main study were measured for five of the six animals used to evaluate heat production in the calorimeter; a hyperactive animal in the calorimeter 48-hr-fasting treatment increased his weight losses considerably above the other animals in that treatment. Calorimeter measures also indicated that urine, feces, and respired

Table 2—Hot carcass wt, apparent carcass wt losses, carcass yields, and liver wt of slaughter hogs fasted or fasted plus transport*

Treatment	Adjusted hot carcass wt, lb	Apparent carcass wt loss, lb	Carcass wt loss as % of livewt loss	Carcass Yield, %		Liver wt, lb
				Adjusted initial wt basis	Adjusted slaughter wt basis	
Control	154.2			73.0	73.2	3.040
24 hr Fast	152.3	1.9	27.9	72.1	74.5	2.744
+ Transport	150.2	4.0	41.2	71.1	74.5	2.749
48 hr Fast	150.2	4.0	31.7	71.1	75.6	2.496
+ Transport	147.5	6.7	44.7	69.8	75.2	2.465
72 hr Fast	148.5	5.7	35.2	70.1	76.2	2.316
+ Transport	144.0	10.2	50.2	68.2	75.4	2.444

*Transport of 435 miles at start of fast period.

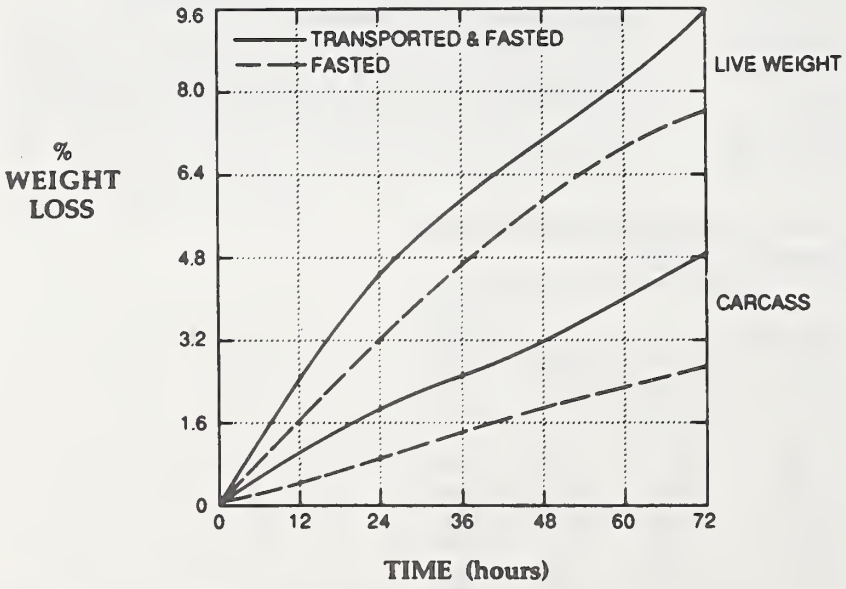

Figure 1—Percent loss of liveweight and carcass wt *vs* hours fasted or transported and fasted.

moisture accounted for 98%, 81%, and 75% of the total liveweight losses for animals fasted 24, 48, and 72 hr, respectively.

The heat production measures indicated a general decline in heat production with increasing time of fast, as would be expected for animals approaching a basal metabolic state. Initial mobilization of body reserves (catabolism) logically involves liver glycogen, an observation supported by liver wt losses measured in the main study animals (Table 2). It is interesting to note that the major shift from carbohydrate utilization to catabolism of body reserves occurred after the first 24 hr of fasting, coinciding with the highest percentage loss of GI tract contents (Table 1). Inactivity (lying down) was the predominant behavioral measure for all fasting treatments in the calorimeter animals, other than the hyperactive hog mentioned earlier. The total number of times getting up and lying down was also highly variable, indicating the lack of food and water affected individuals differently.

Hematocrit values from blood samples suggested that body water losses during the first 24 hr were from the GI tract, while measures at 48 and 72 hr indicated subsequent losses were from body tissue. No significant changes in white blood cell counts occurred as a result of treatments, and the only significant neutrophil:lymphocyte ratio change was a decrease for animals transported and fasted 72 hr. Other physiological changes associated with fasting and transport (decreased plasma triiodothyronine and increased plasma osmolality) suggest a disruption in homeostasis (physiological stability) of the animals.

Carcass weight loss as a result of fasting plus transport for slaughter hogs resulted in a maximum carcass loss of 10.2 lb (72 hr treatment). The most significant changes in the carcass occurred in the decrease in longissimus muscle area, with the transported hogs having muscle areas up to .8 in^2 smaller than muscles from the control animals. Differences in longissimus muscle marbling and last rib backfat were found, but were variable. Despite the smaller longissimus muscle area in the transported hogs, no differences were found for the composition of ham soft tissues. This suggests that carcass loss was not homogeneous throughout the carcass, but rather losses may differ among tissue locations.

Despite the carcass wt loss and the physiological changes associated with the stress of transportation, no detrimental effects attributable to transport were observed for meat quality measures. Taste panel evaluation revealed that juiciness and desirability of pork chops from slaughter hogs were not affected by fasting or fasting plus transport. Cooking wt loss and shear force values of pork chops also showed no effect due to transportation. However, pork chops from hogs transported/fasted for 24, 48, and 72 hr were scored higher in tenderness than chops from control or fasted-only animals.

Interpretation

Our cooperative, multidisciplinary research has definitively evaluated liveweight and carcass wt losses associated with fasting of transported and non-transported slaughter-weight hogs (Fig. 1). The periods of fasting represent a range of marketing situations. These results, which are of use to anyone involved in the marketing process and subsequent slaughter of such animals, show that feed and water deprivation alone accounts for a major portion of liveweight shrink, and more than one-half of carcass wt losses, for periods up to 72 hr. Transport and associated handling during fasting imposes an additional demand on energy metabolism and fluid regulation systems of the animals. This demand results in additional liveweight and carcass wt losses. Concurrent calorimetry measures on similar animals indicated a shift from utilization of GI tract contents to catabolism of liver glycogen and body fat after 24 hr of fasting. The shift to catabolism coincides with the end of the period when the highest percentage loss of GI tract contents had already occurred. However, variations among physiological system responses within individual animals indicate the effect of the additional demand is complex and needs further evaluation.

Fasting caused a decreased carcass yield (initial wt basis) with increased time, but had no measurable adverse effects on meat quality (pH, muscle color score, cooking wt loss, and shearing force of loin chops, or composition of ham soft tissues). Taste panel results indicated that pork chops from transported animals were more tender, while juiciness and desirability were not affected.

Two additional experiments to further examine responses of slaughter hogs to fasting periods of 0, 24, or 48 hr have been completed. A November 1987 experiment was designed to further examine responses reported here for fasting only and fasting plus transport, with an additional factor of mixing of different social groups at the start of the fasting treatment. A September 1988 experiment was conducted in the calorimeters to focus on the source of wt losses during 24 and 48 hr fasting periods. Results of both experiments are currently being evaluated. Another experiment is being planned for 1989 to examine possible differences in responses between heavy (about 240 lb) and light (about 200 lb) slaughter hogs.

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